The receptive language and reading abilities of students diagnosed with auditory processing disorder (APD)

Stephanie Mallen

Bachelor of Applied Science (Speech Pathology)

Department of Speech Pathology and Audiology

Faculty of Health Sciences

School of Medicine

Flinders University

Adelaide, South Australia

Thesis submitted for the degree Doctor of Philosophy
31st March 2010

TABLE OF CONTENTS

ETHICS STATEMENT & DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published by another person except where due reference is made in the text.

The research proposal was approved by the Flinders Clinical Research Ethics Committee (Appendix A). This research was conducted in accordance with the National Health and Medical Research Committee’s guidelines on human experimentation. Subject confidentiality was assured. No subject identification data were placed on any computer system.

Signed…………………………………………….…Date..…/..…/…..

ACKNOWLEDGEMENTS

I wish to acknowledge my present and past supervisors, Dr. Willem van Steenbrugge, Associate Professor Linnett Sanchez and Professor Paul McCormack at Flinders University, South Australia. I also wish to acknowledge my academic advisor in Queensland, Professor Barbara Dodd and her team at the Perinatal Research Institute, Royal Brisbane Women's Hospital. The co-operation of Adelaide Hearing Consultants is also greatly appreciated.

Finally, I would like to thank the kind people who offered their proof-reading services and valuable comments; Associate Professor Sandra Orgeig, Professor Chris Daniels, Dr. Harry Lyndon and Dr. Alexia Lennon.

DEDICATION

I would like to dedicate this thesis to two people. Firstly, I would like to honour the memory of Dr. Ken Rowe, Research Director, Australian Council for Educational Research who tragically lost his life in the 2009 Victorian bushfires. Among his many achievements, Dr. Rowe chaired the independent committee for the National Inquiry into the Teaching of Literacy in 2005 appointed by the Australian Government Minister for Education, Science and Training, Dr. Brendan Nelson. The inquiry received over 450 submissions from concerned parents, health professionals, educators, researchers and politicians. The collated recommendations promote integrated, effective and evidence-based literacy teaching practices in Australian schools for the facilitation of improved literacy outcomes for all students.

Secondly, I would like to dedicate this thesis to my wondrous son, James. Whenever I became dispirited, despondent, despairing or just plain defeated he reminded me to 'just finish it'. Such wisdom in one so young.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADD	Attention deficit disorder
ADHD	Attention deficit hyperactivity disorder
AFG	Auditory Figure Ground subtest
AIT	Auditory inspection task
AM	Amplitude modulation
AP	Auditory processing
APD	Auditory processing disorder
ATOJ	Auditory temporal order judgement
CELF	Clinical Evaluation of Language Fundamentals test
CS	Competing Sentences test
CV, CVC	Consonant-vowel, consonant-vowel-consonant
DRC	Dual Route Cascaded model
DS	Digit Span
FM	Frequency modulation
*f*MRI	*functional* Magnetic Resonance Imagery
FUSAPB	Flinders University standard auditory processing battery
GPC	Grapho-phonemic correspondence
IQ	Intellectual Quotient
ISI	Inter-stimulus interval
LI	Language impairment
LSR	Less skilled readers
LTM	Long-term memory
LTWM	Long-term working memory
NAPD	Non-auditory processing disorder
NARA	Neale Analysis of Reading Ability
NWRT	Nonword Repetition Test
OIL	Orthographic input lexicon

PALPA	Psycholinguistic Assessment of Language Processing in Aphasia
PAPI	Processing Auditory and Print Input model
PIB	Phonological input buffer
PIL	Phonological input lexicon
PPS	Pitch Pattern Sequence test; (LT) Left Total, (RT) Right Total
PPVT	Peabody Picture Vocabulary Test
PWM	Phonological working memory
RA	Reading accuracy
RAN	Rapid automatized naming
RAP	Reading Accuracy Profile
RC	Reading comprehension
RCPM	Raven’s Coloured Progressive Matrices
RD	Reading disability
R = D x C	Simple view of Reading: Reading = Decoding x Comprehension
RGDT	Random Gap Detection Test
RR	Reading rate
SES	Socio-economic status
SL	Sentence Length test
SLI	Specific language impairment
SR	Sentence Recall test
SRD	Specific reading disability
STM	Short-term memory
SSW	Staggered Spondaic Words test
TOJ	Temporal order judgement
WISC	Wechsler Intelligence Scales for Children
WRMT	Woodcock Reading Mastery Test

GLOSSARY

Amplitude modulation (AM) sensitivity - refers to (detection of) changes to the intensity of sound. Modulation is imposed on a carrier wave, varying the amplitude above and below its unmodulated value, but keeping frequency the same.

Auditory Processing- refers to neural processing of the auditory signal; responsible for auditory attention, detection and identification of auditory signals, decoding of auditory input plus storage and retrieval of auditory information.

Auditory Processing Disorder - " a difficulty in the efficiency and effectiveness by which the central nervous system (CNS) utilizes auditory information" (ASHA, 2005)

Central Executive - the control system that allocates attention and supervises the elements of working memory. The central executive regulates what information is stored in long-term memory.

Decoding – the process by which sections (letters or chunks) of the printed word are converted to the phonological equivalent and blended together to form the word prior to recognition of the whole word.

Discrepancy Theory – a method of diagnosing dyslexia based upon a score discrepancy between average or above average IQ scores and reading ability scores greater than 2 standard errors below that predicted by those IQ scores.

Dyslexia – dyslexia is a specific learning disability of neurological origin (The International Dyslexia Association, 2002).The criteria for the diagnosis of dyslexia is controversial. Most commonly, reading ability must be significantly below age expectation with evidence of phonological deficits and/or naming deficits. Lack of reading progress is also a strong indicator.

Encoding- the process by which the spoken word is translated to its print equivalent.

Episodic Buffer – this refers to process within phonological working memory that reactivates prior information, making it available for association with incoming information from the phonological loop or visuo-spatial sketchpad prior to storage in long-term memory.

Frequency Modulation (FM) Sensitivity- refers to (detection of) changes in the frequency of sounds. Modulation is imposed on a carrier wave, varying the frequency above and below its unmodulated value while the amplitude remains constant.

***functional* Magnetic Resonance Imagery (*f*MRI) –** a measure of neural activity (oxygen consumption) while the brain is actively engaged in a task or tasks.

Grapho-Phonemic Correspondence (GPC) - refers to the letter-sound relationship

Intelligence Quotient (IQ) – an IQ score is derived from performance on measures of intellectual ability, standardised against age. The calculation is Mental Age multiplied by 100 divided by Chronological Age to arrive at a score clustered around the mean of 100.

Inter-Stimulus Interval (ISI) – the time interval between two stimuli.

Learning Difficulty – this definition applies when an individual is having diffculty acquiring literacy or numeracy irrespective of intellectual ability.

Learning Disability – this definition applies when an individual has been found to be of average intelligence yet has a specific difficulty with reading (dyslexia), spelling/writing (dysgraphia) or calculation (dyscalculia).

Less Skilled Readers (LSR) – refers to readers who are performing below expectation for age but do not fulfil the criteria for dyslexia. Both poor decoding and comprehension are common.

Long Term Memory (LTM) – the repository of processed information available for retrieval once activated.

Matthew effect - refers to the reciprocal relationship whereby the benefits of reading ensure that good readers become even better readers while less-skilled readers fall further behind. The effect is not simply that 'the rich get richer' but rather that readers create a reading environment that promotes greater reading experience e.g. sharing books and stories, requesting books as presents etc.

Mismatch Negativity - abnormal brainstem responses linked to susceptibility to noise and also reduced sensitivity to acoustic changes.

Orthography – the printed symbols (letters) that represent speech sounds

Phonological mediation – the conversion of letter symbols or written words to their corresponding phonology *after* recognition, either silently or spoken aloud. Decoding may or may not be involved *before* recognition (see Decoding).

Phonological representations - the neural representations of speech sounds, in isolation (e.g. 'p') or as whole words (e.g. 'parallel')

Phonological Awareness – refers to knowledge regarding the sound structure of the language. Phonological awareness skills include rhyming, syllabification, sound segmentation, blending and manipulation.

Phonological Working Memory (PWM) – when auditory short term memory capacity has been exceeded or when verbal information requires manipulation, the information enters the phonological working memory system, where it is processed while presided over by the central executive.

Prosody – the suprasegmental features of an utterance e.g. rhythm, stress and intonation. These features convey information about the speaker’s intention and emotional state.

Rapid naming or Rapid Automatized Naming (RAN) – the rapid (spoken) retrieval of the correct label for an object, picture, letter, symbol or word

Recoding – the process by which known letter-sound correspondences are modified to incorporate more complex correspondences e.g. ‘s’ correspondence is modified to incorporate the digraph variation ‘sh’. Often used in relation the complex process of vowel recoding e.g. ‘o’ correspondence must be modified to incorporate ‘oo’, ‘oa’, ‘ou’, ‘ow’ etc.

Specific Reading Disability (SRD) – this term is usually applied to determine eligibility for special education funding. SRD is usually diagnosed when reading ability is significantly below (by 2 years or alternatively 2 standard deviations) expectation for age. Persons diagnosed with SRD may be dyslexic or less-skilled readers (LSR).

(Auditory) Temporal Order Judgement (ATOJ/TOJ) – refers to the ability to retain the sequence of auditory information and make accurate responses pertaining to that sequence.

Abstract

This study hypothesized that students with a diagnosed auditory processing disorder (APD) will exhibit significantly greater auditory processing deficits (including phonological working memory), receptive language and reading difficulties compared to a non-APD group (NAPD) in Study One and significantly greater receptive language and reading difficulties compared to a reading-age matched Average reader group in Study Two. A relationship between the degree (severity) of auditory processing deficits and both receptive language and reading ability was also hypothesized. Further, it was hypothesized that the pattern of reading errors exhibited by students with APD will show differences compared to the reading error pattern of the two groups of students without APD. Participants in Study One had already undergone a diagnostic battery of auditory processing assessments. The participants in Study One underwent further assessments of auditory processing including auditory figure-ground, temporal gap detection, pitch perception and auditory sequencing. The Average reader group in Study Two was screened using the Sentence Length test, a screening tool designed to identify children who may be at risk of an auditory processing disorder. For both Study One and Study Two the *CELF:Listening to Paragraphs* subtest and *Peabody Picture Vocabulary Test-3* were administered followed by subtests of the *Woodcock Reading Mastery Tests-Revised* and the *Neale Analysis of Reading Ability-3*. The reading tests cover letter naming, grapheme-phoneme conversion, word identification, word attack and text reading. In Study One, the APD group exhibited significantly poorer phonological working memory (PWM), but not significantly different receptive language or reading abilities than the NAPD group. Interhemispheric transfer deficits, as demonstrated on dichotic listening tasks, were significantly correlated with PWM performance. PWM ability was significantly correlated with receptive vocabulary, listening comprehension and reading comprehension abilities. The severity of AP deficits was correlated with phonological working memory and receptive vocabulary. The results also suggest a contribution of non-speech auditory processing deficits (frequency discrimination) to PWM and word reading abilities. In Study Two, the APD subgroup exhibited significantly poorer receptive language and reading abilities (based on standard score performance) compared to the reading-age matched Average reader group, matched on raw scores. Again, PWM was significantly correlated with receptive vocabulary, listening comprehension and reading comprehension in the APD subgroup. Reading errors made by the participants with APD were less likely to retain the intended meaning of the text, compared to the NAPD group in Study One. In Study Two, the APD group made as many errors that lost the intended meaning of the text as the significantly younger reading-age matched Average reader group. Analysis of error types in the APD group showed a greater number of whole word substitutions of meaning and word shape and fewer recasting and decoding errors compared to the Average group. The study supports a relationship between auditory processing deficits, phonological working memory and both receptive language and reading abilities.

CHAPTER ONE

Introduction

1.0 Statement of the Problem

The effect of auditory processing deficits upon reading development or reading performance in children has not been clearly established (Cacace & McFarland, 1998; Rosen & Manganari, 2001; Rosen, 2003). This study aims to contribute to our knowledge of the relationship between auditory processing deficits and reading performance. Reading research has identified various factors that may be responsible for or at least are associated with reading difficulties. Factors most commonly considered are deficits in auditory processing, visual processing, intellectual ability, phonological working memory, language, phonological awareness, word identification and attention. The critical role of phonological awareness skills for reading success was highlighted by researchers such as Bradley and Bryant (1983) and Liberman and Shankweiler (1985). This perspective has dominated reading research in the past two decades, leading to significant changes in teaching approaches and assessment protocols of speech pathologists and psychologists working in the field of education (Lundberg, Frost & Petersen, 1988; Torgesen, Wagner & Rashotte, 1994; Center for the Improvement of Early Reading Achievement; National Institute for Literacy, 2003; Gillon, 2004). In contrast, research investigating the role of auditory processing in reading development and reading performance has been less influential and this is partly due to the fact that findings have been more inconsistent (Mody, Studdert-Kennedy & Brady, 1997; Cacace & McFarland, 1998; Rosen, 2003). It is important that the role of auditory processing in reading development and reading performance be further investigated and better understood.

Auditory input is transient and therefore susceptible to fading whereas written input is a permanent and non-fading referent. Given that silent reading does not directly involve auditory input it is necessary to explain why the relationship between auditory processing and reading is relevant. Proficient reading is multi-modal and relies upon rapid visual word recognition, efficient phonological decoding and language comprehension. All reading relies upon stored phonological and linguistic information, which has developed primarily as a result of input, received predominantly via the auditory mode in the early years. Reading involves phonological mediation of the written word such that both decoding of single words and sequential phonological mediation of text is subject to the same integration and retrieval processes as auditory input, including phonological working memory. Reading aloud creates external auditory input that is subject to auditory processing and again, phonological working memory. When investigating the relationship between auditory processing and reading ability, it is also necessary to investigate phonological working memory and language abilities.

Central to the current study is the understanding that learning to read is an incremental process that includes acquiring linguistic knowledge and associated phonological representations and acquiring increasingly efficient decoding skill and comprehension strategies. For this reason, potential insights that can be gleaned from reading errors will also be investigated in this study. The degree to which reading abilities are influenced by auditory processing relative to the influence of higher level linguistic processing is also critical and will be reviewed in the next chapter.

Studies investigating the role of auditory processing abilities in reading have focused on identifying auditory processing deficits in groups with known reading difficulty. Despite the wealth of research conducted in this area, there is no firm conclusion on the role of auditory processing deficits in reading (Rosen, 2003). Some studies have concluded that no relationship exists between auditory processing abilities and reading achievement (Watson, Kidd, Horner et al., 2003) while others have confirmed a link between auditory processing and reading ability (Banai, Hornickel, Skoe et al., 2009). There is a range of impairments that lead to reading difficulty therefore it is unlikely that consistent auditory processing deficits will be found in all individuals with reading difficulty.

The present study postulates that auditory processing deficits have a negative impact on reading performance, but are not the sole cause of reading difficulty. Skilled text reading is a conglomeration: visual, linguistic and cognitive processes working together with reading comprehension as the end point. A greater understanding of the role of auditory processing skills and deficits in reading development will lead to improved differential diagnoses of reading difficulty. Furthermore, a better understanding of how auditory processing deficits contribute to reading breakdown is crucial for the implementation of better approaches to the teaching of reading and improved intervention practices for the remediation of reading difficulties.

1.1 Theoretical Basis of the Study

1.1.1 Psycholinguistics

Psycholinguistics focuses on studying behaviours related to language. The sub-fields of psycholinguistics encompass the study of grammar and syntax, bilingualism, pragmatics, the relationship between language and thought and the psychology of reading (Reber, 1985). Developmental psycholinguistics focuses specifically on language acquisition. The nature of language development necessitates the involvement of cognitive processes such as attention, memory and information processing and therefore, these underlying processes are also studied by psycholinguists. This study is therefore a psycholinguistic study investigating the relationship between the pre-requisite skills for reading and reading performance. The field of psycholinguistics also contributes a framework for the information processing required for word reading to this present study. Reading development can be viewed from at least three different theoretical standpoints which will be outlined here.

1.1.2 Cognitive Theory

Cognitive theory holds that observable linguistic behaviour can be explained by mental processing of information via attention, motivation, thought processing (e.g. decision-making) and language processing. Cognitive theory presumes that proficient reading culminates from efficient information processing. The purpose of reading is to gain meaning from text. Therefore, the ‘information’ of reading is the content and ‘processing’ refers to the processes directed at the goal of gaining meaning from that content (Reber, 1985). Models of information processing typically share common components and stages which may include:

1. A structural component – representing the physical constraints of the system e.g. storage capacity;
2. A strategy component – representing the stages of the system in operation e.g. processing;
3. An executive component – representing the monitoring of the system e.g. attention, vigilance, motivation.

The three components above combine to form the potential that an individual has to perform a task.

1.1.2.1 Structural component

The capacity theory proposes one explanation for limitations of the structural component (Just & Carpenter, 1992). When spoken input processing requires a large amount of cognitive demand, then there will be less capacity available for contextual processing, representing a trade-off between capacity and load (Medwetsky, 2002a). When word decoding in reading requires a large amount of cognitive demand then comprehension may be compromised (Shankweiler, 1989). When semantic retrieval requires a large amount of cognitive demand then phonological working memory may be compromised and less new information may be stored in long-term memory during listening or reading comprehension tasks. If these processing tasks are further compromised by weak phonological representations and/or weak semantic representations this would further increase the overall cognitive demand required for information processing. During oral or reading comprehension tasks, a finite amount of cognitive activation can take place for any individual at one time and therefore, the amount of activation available for any one process will be restricted by how much activation or cognitive demand is required for another process. This is the structural component.

Cognitive theory recognises the importance of phonological working memory as being critical for information storage. Storage occurs at the same time that meaning from incoming spoken or written information is being constructed, using the available higher level semantic, syntactic and pragmatic information in long-term memory. For instance, the main idea of the text, its references and interactions must be progressively retrieved from long-term memory and placed in working memory (Just & Carpenter, 1992; Medwetsky, 2002a). When information processing is efficient new information is readily stored. When information processing is poor due to auditory processing difficulties or weak language skills, overall functional capacity will be limited. Auditory processing deficits may be one reason for the development of weak phonological and semantic representations creating load within phonological working memory. This will have an impact on the efficiency of the strategy component described below.

1.1.2.2 Strategy component

Numerous information processing models have been proposed for spoken language (Swanson, 1987; Medwetsky, 2002a) and/or reading (Ellis & Young, 1988; Howard & Best, 1996; Stackhouse & Wells, 1997). All of these models have components in common which are presented here within the multi-store model (Butler, 1983). The multi-store model assumes a flow of information from the sensory register through short-term memory to long term memory. The four stages of the multi-store model are briefly described as follows:

1. Input- the sensory input, such as visual or auditory input;
2. Integration – the coding, sequencing and categorisation of auditory information. At this stage the individual applies strategies aimed at assisting information processing. Short-term memory, phonological working memory and retrieval processes are essential components of this processing stage. Strategies may include repeating information by retrieving existing phonological representations and/or condensing meaning by retrieving existing semantic information from knowledge of the world. The product is the perception or interpretation of the sensory information received ;
3. Storage – the selective storage of the interpreted information in long-term memory as the final stage of input processing;
4. Output – refers to the organisation and delivery of linguistic output in the form of spoken language, reading aloud or writing (e.g. answering comprehension questions).

   (Swanson, 1987):

Information is transformed at each stage and the product of that transformation is passed to the next stage. The quality of the input available to the next stage is dependent on the operations of the preceding stage. Poor quality input (sensation or perception) or weaker processing operations will result in a disorder[1] or impairment[2] of information processing. Inefficient information processing has a detrimental impact on new learning and comprehension.

1.1.2.3 Executive component

Briefly, the executive component allocates attention, cognitive abilities and working memory to the task and monitors the levels of attention, vigilance and motivation for the duration of the task. The executive component is discussed more fully in section 2.3.

1.1.3 Biological Theory

Biological theory views reading performance as a reflection of neurophysiological functioning. In the case of reading, neurophysiological deficits in brain function are considered to lie predominantly in linguistic functioning, auditory functioning and visual functioning. In recent years, the accessibility of functional magnetic resonance imagery (*f*MRI) has enabled

---

[1] A disorder is defined as a ‘derangement or abnormality of function’(*Dorland's Pocket Medical Dictionary*, 1995)

[2] An impairment is defined as a ‘weakening, damage or deterioration (especially as a result of injury or disease)’ (*Stedman's Medical Dictionary*, 2005)

researchers to view the active cortices of the brain while performing tasks of speech, language, reading or spelling. From these studies, the left inferior occipito-temporal region, left temporo-parietal region and left inferior frontal regions show high levels of activation during normal word reading (Aparicio, Gounot, Demont & Metz-Lutz, 2007). Specifically, *f*MRI studies have confirmed involvement of the extrastriate visual cortex, fusiform gyrus, superior temporal gyrus, inferior parietal region, white matter connectivity between the posterior and frontal regions and the inferior frontal cortex (Broca's area) during the reading task (Joseph, Noble & Eden, 2001; Booth & Burman, 2005). These areas are involved in visual word and letter recognition, naming, processing of auditory temporal information (including phonological processing) and integration of the auditory, visual and linguistic information.

1.1.4 Behavioural Theory

Behavioural theory views reading performance as a trained activity, developed through experience (Westen, 1999). The reading behaviour of an individual is measured and compared to the normal distribution of an age group or a group defined for a specific purpose such as a year level class of children or research group. Due to the high value placed on literacy in Western societies, a less-skilled reader is seen as deficient or in severe cases, as having a disability. Behavioural theory adheres to what can be observed and measured though most behaviourists do not reject cognitive theories that embrace covert internal states, processes and motivations.

1.1.5 Summary of the Theoretical Basis for this Study

The present study is particularly interested in information processing, the domain of cognitive theory. However, the data were obtained from behavioural observations of performance. Studies reporting neurophysiological evidence will be discussed where relevant. Therefore, the study spans cognitive, biological and behavioural theories. Critical to the interpretation of this research is the degree to which reading accuracy and reading comprehension is influenced by the perception and integration of auditory information on the one hand and higher level linguistic processes on the other hand. If speech and language processing is purely a bottom-up process, processing of the information begins with the perception of sounds and then progresses to higher level linguistic constructions. This is often referred to as a data-driven approach or auditory-perceptual pathway model. Deficits in auditory processing at the stages of perception, integration or phonemic-phonologic analysis will have an impact upon higher level linguistic analysis (Chermak & Musiek, 1997). If speech and language processing is a top-down process then spoken information is understood by the application of cognitive and linguistic processes that determine the probabilities of what has been spoken. This is a concept-driven approach, often referred to as a network model or linguistic-cognitive model (Duchan & Katz, 1983). The network model takes in to account world knowledge, recognition of expected patterns and allocation of attention to processing (Dawes & Bishop, 2009). The bottom-up approach is referred to as the audiological viewpoint and the top-down approach as the psycholinguistic viewpoint. The predominant understanding is that both top-down and bottom-up processes are integral to efficient information processing and occur interactively and simultaneously. Both auditory and linguistic processes are therefore influential upon language and phonological development (Bellis, 2003). What is experienced by the listener is an *auditory perceptual event* (Tyler, 1992): an interaction of the auditory stimulus with higher level auditory and linguistic processing, attention, memory and cognition. Even the lowest stages of auditory analysis do not operate independently of top-down processes, nor do the higher level stages of linguistic prediction operate independently of bottom-up processes.

CHAPTER TWO

Literature Review

2.0 Structure of the Literature Review

This literature review presents the current thinking on the normal reading process and contrasts this with what is known about reading difficulty. The psycholinguistic models of word reading, accepted in reading research, are then explained. The current knowledge of the performance components of reading are dealt with in detail, with particular attention paid to the relationship to auditory processing. A review of the research in regard to reading errors is then provided. The review concludes with an overview of the significance of the present study, a summary of the present study and the specific aims and hypotheses.

In summary, the literature review addresses the core components in the following order:

- normal reading and reading difficulties
- models of reading
- role of the central executive; attention, phonological working memory and cognition
- auditory processing and auditory processing disorder
- receptive language and related performance components; listening comprehension and long-term memory storage, vocabulary acquisition and the semantic system

- word reading and related performance components: naming and phonological awareness
- word reading errors
- sentence reading and related performance components: syntactic system, reading comprehension
- sentence reading errors
- significance of the study
- summary of the present study
- specific aims and hypotheses

2.1 Reading Overview

Unlike the acquisition of spoken language, learning to read is not an innate process. Evidence of written language systems dates no farther back than 2,500 years and this is not considered to be a sufficient time-span for the processes of natural selection and evolutionary change to develop innateness (Coltheart & Leahy, 1996). Furthermore, literacy education was not the norm until the mid 19th century. Even the skill of visual convergence in which both eyes fixate on a close stimulus is so recently evolved that it is readily vulnerable to breakdown under the influence of drugs (including alcohol) or illness (Stein & Talcott, 1999). Consequently, there are no critical periods for learning to read. Reading is skill-based, in much the same way that sporting, musical or artistic skills are learned. In each case, certain biological, physiological, environmental or behavioural factors can hinder or alternatively, predispose the individual to a degree of skill proficiency.

2.1.1 Normal Reading

Normal reading is acquired by 90-97% of students who enter schooling in the First World (Organisation for Economic Co-operation and Development [OECD], 2000). Proficient reading requires accuracy, fluency and comprehension (Weaver, 1994). The information processing skills necessary for the task include attention to the task, perception of the written symbols in rapid succession, conversion of the written symbols to the phonological representation, access to the meaning of the lexical items or concepts being conveyed and when reading aloud, ability to plan and execute the necessary motor sequences. The more rapidly these functions are performed, the more fluent the reader.

It is often promulgated that literacy immersion and regularly reading aloud to children will promote normal reading development yet studies show that no greater than 10% of the variance in reading outcomes can be attributed to reading exposure in the home (Lundberg, 2002). Reading aloud to children has the obvious benefits of emotional enjoyment, exposure to literate language and literacy materials, exposure to new vocabulary items as well as value being placed on the literacy task by significant others in a child’s life. For instance, Cunningham and Stanovich (1991) found that individual differences in vocabulary performance in children could be predicted from familiarity with popular children’s book titles. Gathercole, Willis, Emslie and Baddeley (1992) also found that reading ability at 6 years of age was strongly correlated with vocabulary two years later. Nevertheless, shared book experiences cannot safeguard a child from encountering reading difficulty. Scarborough, Dobrich and

Hager (1991) compared children who became disabled readers (n = 22) and those who did not (n = 34) in a prospective study. There were no significant differences between those children read to once or more on a daily basis by their mothers at ages 2½, 3, 3½ or 4½ years of age. In contrast, early language skills, emergent literacy skills and interest in literacy were much stronger predictors of literacy outcomes (Scarborough & Dobrich, 1994). In a review of seven studies, Scarborough and Dobrich (1994) concluded that reading to preschoolers and reading outcomes were associated, but with a median co-efficient of 0.28. Taking all other tested variables into account, no more than 8% of the variance in achievement could be attributed to this factor. The low correlations between reading in the home and successful reading outcomes strongly indicate that normal reading development cannot be entirely attributed to reading behaviours in the home.

Early reading is understood to follow the three stages outlined by (Frith, 1986) in which a few words are initially recognised by sight during the logographic stage, followed by the gradual acquisition of letter-sound correspondences in the alphabetic stage before direct visual access in the orthographic stage. In the latter stage syntactic and semantic features are also employed to assist reading fluency. Frith emphasised that in each stage the reading strategies employed are different and that progression through the stages does not necessitate loss of an earlier stage. A reader may be using orthographic strategies predominantly, yet continue to use letter-sound correspondences whenever an unfamiliar word is encountered, perhaps ‘curmudgeonly’ or ‘consanguineous’. Note that it is unlikely that a proficient reader would decode either of these words by corresponding each single letter to its phonological counterpart. It is more likely that some ‘chunking’ will occur e.g. ‘ur’, ‘dge’ etc. The aim of proficient reading is to acquire rapid and accurate visual recognition of words thus allowing rapid semantic access to occur. The reader can then read both fluently and with meaning. Competent adult readers use logographic, orthographic and alphabetic strategies upon encountering unfamiliar words or nonwords, including low frequency proper nouns such the name ‘Siobhan’ or the place ‘Langkawi’. For instance, the logograph ‘Siobhan’ may be recognised by sight and this activates the paired phonological representation ‘Shevawn’, whereas letter-sound correspondence may be used to work out an acceptable pronunciation of ‘Langkawi’.

2.1.2 Reading Difficulties

The majority of students who enter schooling in developed countries achieve literacy, many seeming to do so effortlessly. Unfortunately, for too many this is not the case. Reading *disabilities* are estimated to affect about 3 percent of students with about a further 10% of students affected by reading *difficulties* (Snowling, 2000a). In low socio-economic settings in the United States, the number of students experiencing literacy failure is estimated to be as high as 70% (National Center for Education Statistics, 1998). The United States now considers its literacy problems to be a major public health concern with an estimated one in five students, equating with about 10 million children experiencing reading failure as determined by a National Institute of Child Health and Human Development (NICHD) longitudinal study (Lyon, 1999, 2001).

2.1.2.1 Dyslexia

Dyslexia will be briefly outlined for the purpose of distinguishing this group of poor readers from the less-skilled reader group that is of interest in this study. Dyslexia is typically diagnosed when there is a significant reading deficit in the absence of any intellectual impairment, sensory impairment or apparent disadvantage due to cultural, environmental or educational factors. The International Dyslexia Association defines dyslexia thus:

> Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede the growth of vocabulary and background knowledge.
>
> (2002, online factsheet)

An epidemiological study by Rutter and Yule (1975) was influential in the emergence of the discrepancy theory for dyslexia. Where the intelligence quotient (IQ) fell within the normal range but reading ability was greater than 2 standard deviations below that predicted by IQ, a ‘discrepancy’ existed and dyslexia was diagnosed (Vellutino, Scanlon & Lyon, 2000). Rutter and Yule’s large-scale population study determined that where *both* IQ and reading ability fell below one standard deviation, this was described as general reading backwardness. Using the discrepancy theory for diagnosis in an epidemiological population study, dyslexia affects about 3-6% of 10 year-olds in the population (Rutter & Yule, 1975; Snowling, 2000a). The prevalence figures across age groups vary widely, depending on the intellectual and reading measures used to determine the reading deficit. The gender ratio of *dyslexia* diagnosis is 3.3 males:1 female (Rutter & Yule, 1975).

Use of the discrepancy approach has come under scrutiny and its validity has been impugned (McDougall & Ellis, 1994; Snowling, 2000a; Vellutino et al., 2000; Vellutino, Scanlon, Small & Fanuele, 2006). Initially much debate centred on whether reading age should be compared to non-verbal IQ alone or both verbal and non-verbal IQ to determine the discrepancy. Foremostly, correlations of full-scale IQ or non-verbal IQ to reading ability have not been high (Siegel, 1988; Stanovich, 1991). It is argued that if verbal IQ is not taken into account, then low verbal abilities may blur the diagnosis of dyslexia with readers who have concomitant language difficulties that may be a contributing cause of low reading ability (Stanovich, 1993). However, if verbal IQ is included, language difficulties will lower overall IQ scores and a diagnosis of dyslexia may be overlooked.

Vellutino et al. (2006) expressed further concerns regarding the use of a discrepancy criterion for dyslexia which include that:

1) pre-school experiences and educational history is not taken into account
2) the relationship between skills assessed on IQ tests and reading ability have not been well established

3) undue weight is given to the IQ performance rather than reading performance

They summarise that it would be preferable to utilise ‘at risk’ measures that have established links to reading ability and provide intervention according to the deficits, especially in the early years of schooling to prevent reading failure. Ultimately, clear criteria to separate dyslexic from non-dyslexic readers based on distinguishable features may be more useful, with additional severity measures in each case.

2.1.2.2 The genetic and neurological basis of dyslexia

The evidence for anatomical, physiological and genetic differences in dyslexia has been mounting. Dyslexia has long been noted to be heritable and a gene marker has now been located on chromosome 6 (Snowling, 2000) and also implicated on chromosome 15 (Field & Kaplan, 1998), a chromosome that has also been linked to word identification ability (Lyon, 1999). Scarborough’s work (1990) demonstrated that 65% of children born in a family with a history of dyslexia were classified as reading disabled at 8 years of age (based on a criterion of ≥1.5 SD below age peers on reading tasks). Gallagher, Frith and Snowling (2000) obtained similar results with 57% of children with a family history of dyslexia experiencing a delay in literacy development at 6 years of age. These family studies have also shown a remarkably even distribution of dyslexia across gender. While dyslexia is *diagnosed* in more boys than girls on a ratio of about

3:1 there is now evidence to show that the reading ages of boys generally are lower than girls, especially in the early years of schooling and therefore, there is a risk of over-diagnosis of dyslexia in boys when arbitrary cut-off points are used for diagnosis (Snowling, 2000a).

Using functional MRI studies Shaywitz (1996) demonstrated activation of the extrastriate cortex in the occipital lobe during letter identification, the left inferior frontal gyrus (Broca's area) during phonological tasks and the middle and superior temporal gyri during phonological and language processing in normal readers. In contrast, under-activation or absent activity of the left temporoparietal cortex, superior temporal gyrus, angular gyrus and inferior frontal gyrus during phonological processing tasks has been reported in readers with dyslexia (Shaywitz, 1996). Prefrontal activity during processing of rapid auditory stimuli has also been found to be absent in dyslexic individuals. Subsequent studies have shown greater activation of the right hemisphere than the left hemisphere during word recognition tasks by dyslexic readers. Furthermore, dyslexic symptoms have been evident in split-brain studies and cases where the left cerebrum has been removed. In summary, *f*MRI studies indicate under-activation in the left hemisphere regions responsible for letter recognition, phonological and linguistic processing and over-activation in the right hemisphere during reading tasks in the dyslexic population.

2.1.2.3 Features of dyslexia

The majority of readers with dyslexia exhibit an impairment of the non-lexical (phonological) route *and* the lexical route of Coltheart's dual-route reading model. This is referred to as a 'double deficit' under the double-deficit theory proposed by Wolf and Bowers (1999). Dyslexic individuals with a double-deficit have difficulties with the recognition of both irregular and regular real words as well as nonwords. The term ‘deep’ dyslexia has been used for this group (Stothard & Hulme, 1995; Vellutino, Scanlon & Spearing, 1995; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). This group is the most severely impaired and is also generally the most unresponsive to current intervention methodologies. There is now accumulating evidence that deep dyslexia could be the consequence of right hemisphere reading (Coltheart et al., 2001). Clinically, dyslexic readers present with the primary concern being lack of progress despite solid educational input and often additional intervention. The observation of dyslexia typically includes noticeable struggle, effort or frustration reading real words, including regular high frequency words and function words and an inability to access the phonological code to assist reading, even with isolated letters. Nonword reading is particularly difficult (Snowling, 2000a). Rapid automatic naming (RAN) of pictures, letters and words is typically poor (Bowers, Steffy & Tate, 1988; Badian, 1997; Wolf, Bowers & Biddle, 2000). Letter and word confusions are frequent as are sequencing errors. Real word errors may be semantic eg. ‘pond’ for ‘lake’, visual eg. ‘was’ for ‘saw’ or morphological eg. ‘run’ for ‘running’.

There are two ‘single deficit’ forms of developmental dyslexia. Children may exhibit developmental phonological dyslexia whereby whole word recognition (the lexical route) is developing normally but phonological conversion (the non-lexical route) is impaired. Alternatively, children may exhibit developmental surface dyslexia whereby phonological conversion (the non-lexical route) is developing normally but whole word recognition (the lexical route) is impaired (Coltheart et al., 2001). Other forms of dyslexia are acquired following brain injury and will not be discussed here.

In contrast, underactivation of the left inferior frontal gyrus (Broca's area) in dyslexic individuals during phonological tasks is suggestive of reduced *access* to the phonological representation of letters and words (Goswami, 2000). The reader must convert the orthographic symbols to phonological information that then enters working memory, but in the case of dyslexia this conversion may be slowed due to phonological deficits, causing loss of information from working memory and ultimately affecting accuracy and comprehension of the text. Normal adult reading rate is about 120 to 200 words per minute but when a normal adult reader deliberately reads slowly, comprehension is affected due to the rapid loss of pieces of information from working memory and loss of efficient sentence parsing (Shankweiler, 1989). The experience is similar to the effect on listening comprehension when listening to someone who is talking very slowly. A further explanation follows:

> ...we can readily appreciate the connection between poor decoding and poor comprehension when we see that phonological processing limitations create a kind of bottleneck that limits the assimilation of lower level language structures into higher level ones. Because working memory has a small capacity and decays rapidly, it must receive new material at a rate that is neither too fast nor too slow in order to function well in language understanding. (Shankweiler, 1989, p.62)

It is important to note that when a skill such as phonological processing is dysfunctional, other skills are likely to compensate, such that whole-word recognition may become the predominant reading strategy for individuals with developmental phonological dyslexia (Frith, 1986). Evidence from computer generated simulated reading indicates that whole-word recognition may be linked to semantic representations rather than phonological representations (Snowling, 2000a). The evidence suggests that over time, dyslexic readers may be able to establish better orthographic-*semantic* mapping than non-dyslexic readers (who rely more strongly on orthographic-*phonologic* mapping), with many achieving normal levels of reading comprehension in later years especially when language skills are strong (Snowling, 2000a). Snowling (2000a) argued that language skills may be a better predictor of long-term reading success than severity of dyslexia. Weaver (1994) also supported this view, proposing that “accuracy in word identification is less important in proficient reading than being able to co-ordinate various language cues and metacognitive strategies to construct meaning” (p.23).

The literature reports that readers with dyslexia consistently show deficits in rapid automatized naming (RAN) of pictures, letters and words (Vellutino et al., 1995; Badian, 1997; Wolf et al., 2000), phonological awareness (Torgesen et al., 1994; Stothard & Hulme, 1995), short-term auditory memory tasks (Jorm, 1983; Shapiro, Nix & Foster, 1990; Metsala, 1999), reading of nonwords (Coltheart, 1978; Vellutino et al., 1995) and repetition of nonwords (Gathercole & Baddeley, 1993). It is the task for researchers to understand how these skills inter-relate for those individuals with dyslexia, both of the surface and phonologic type.

2.1.2.4 Less-skilled readers (LSR)

Gough and Tunmer (1986) first proposed the simple view of reading , where reading (R) is not simply the addition of decoding (D) and comprehension (C), but the product of the two factors i.e. $R = D \times C$ in the normal population. In normal reading, decoding and comprehension are positively correlated, with the correlation increasing exponentially as skills improve; it is not merely a word-by-word process of ‘decode plus comprehend’ then repeat for the next word etc. To support this, reading accuracy and reading comprehension have shown a lower non-significant correlation ($r = 0.145$) at 7 years of age ($n=102$) and a higher significant correlation ($r = 0.407$) at 8 years of age ($n=102$) in samples of children described as ‘relatively unselected’ by the researchers (Oakhill, Cain & Bryant, 2003). However, for the simple view to be correct, decoding and comprehension would need to be negatively correlated in the population with reading difficulties. This would seem to be the case. An individual with dyslexia may have average listening comprehension abilities, but will have poor reading comprehension because of their decoding difficulty. Conversely, individuals with hyperlexia are able to decode well, but exhibit poor reading comprehension. Consequently, decoding and comprehension are negatively correlated in these instances. The value of the simple view of reading is that it highlights that decoding and comprehension are discrete abilities. When both decoding and comprehension appear to be poor, the correlation on performance may seem to be positive, but this is deceptive. According to Gough and Tunmer phonological proficiency allows development of decoding skill while verbal proficiency allows comprehension skill. The conclusion was that proficient reading requires efficient decoding of each word in the stream in order for comprehension processes to act on that stream. The simple model of reading demystifies the types of reading difficulties thus:

> It follows that there must be three types of reading disability, resulting from an inability to decode, an inability to comprehend or both. It is argued that the first is dyslexia, the second hyperlexia and the third common, or garden variety, reading disability. (Gough & Tunmer, 1986, p. 6)

It is the third group that is of interest in this study. This study is interested in pursuing whether there is evidence to suggest that auditory processing deficits impair phonological representations which may explain some of the features observed in this group. Whereas students with dyslexia are known to have marked difficulty with letter and word recognition, rapid naming of pictures and core phonological processing difficulty, a further 4 to 7% of students with*out* dyslexia experience under-achievement in their reading development (Snowling, 2000). These readers usually experience poor comprehension, often but not always accompanied by low word recognition and weak decoding. As in the example above, this group have been referred to as ‘garden-variety’ reading disability, poor readers, backward readers, retarded readers, reading-disabled or mixed reading disability in the literature (Gough & Tunmer, 1986; Stanovich, 1991; McDougall & Ellis, 1994; Catts, Hogan & Adlof, 2005). The term ‘less-skilled readers’ (LSR) will be used in this study and the term ‘poor’ readers will be used when the criterion for poor reading status in the literature is not clear.

LSR perform below the average on tests of reading ability, yet do not meet the criteria for dyslexia. Males and females are equally represented as LSR (Rutter & Yule, 1975). As with APD, LSR are commonly reported to have lower verbal or full-scale IQ than students diagnosed with dyslexia. Lower vocabulary has also been reported in LSR compared to readers with dyslexia (Swan & Goswami, 1997b). The reading abilities of LSR are also sometimes considered to be analogous to younger readers (Stanovich, 1993). A major distinction is that LSR differ prognostically from readers with dyslexia, with the former making better progress across a 4-5 year period (Yule, 1973; Rutter & Yule, 1975).

The features of LSR have been less rigorously researched than the features of dyslexia. LSR commonly evince auditory short-term memory deficits, phonological deficits and language deficits (Brady, Shankweiler & Mann, 1983; Liberman & Shankweiler, 1985; Stanovich, 1988). Frequently, the phonological deficits are less severe than in readers with phonological or deep dyslexia, reading of nonwords is less problematic and substantial rapid naming difficulties are absent (Howard & Best, 1996). Letter-to-sound conversion may be slow either due to phonological deficits or poor orthographic knowledge (Coltheart & Leahy, 1996).

Crain (1989) proposed two views on disorders of reading. One view, called the *processing limitation hypothesis* sees reading difficulties to be the consequence of difficulties processing phonological information. The other view, called the *structural deficit hypothesis* sees reading difficulties as a consequence of language difficulties. Another way of looking at this is to consider reading difficulties to be either code-based or meaning-based (Vellutino et al., 1995). The reading deficits of LSR are code-based *and* meaning-based whereas readers with dyslexia have predominantly more severe code-based difficulty. Catts, Adlof and Weismer (2006) divided LSR into two groups: ‘poor decoders’ and ‘poor comprehenders’ in their support for the simple view of reading. Poor decoders have poor visual word recognition, but good comprehension whereas poor comprehenders exhibit poor comprehension, but good visual word recognition. Some readers fulfil the criteria for both descriptors and these readers have a mixed profile i.e. poor word recognition and comprehension. These divisions make it clear that LSR are not a homogenous group. Any research group of ‘poor readers’ may therefore contain both poor comprehenders and poor decoders (possibly including dyslexic readers) unless one or the other has been specifically identified and excluded. It would seem most likely that LSR are a ‘mixed bag’ of individuals: some with attention difficulties, lower cognitive abilities, auditory processing difficulties, visual processing difficulties, phonological difficulties and language processing difficulties either discretely or in combination.

2.1.2.5 A note regarding subject selection

In the studies to be reviewed in the following sections there exist complications of participant comparison. Confusion arises when reviewing the reading research because the terms reading disability, specific reading disability (SRD), dyslexia, reading difficulty, ‘good’ readers versus ‘poor’ readers are all used, sometimes without criteria for inclusion in the category specified. The most common criteria for subjects in these reading impaired groups include:

- reading ability on any one or a number of reading measures being 1 or 2 standard deviations below the mean for chronological age;

- reading ability 1 or 2 years below grade level;
- reading ability has met the diagnostic criteria for specific reading disability (SRD) or dyslexia.

Comparisons across studies are further complicated when the criteria by which SRD or dyslexia was diagnosed is absent in the literature. To make a point, when a discrepancy between intellectual ability and reading performance is used to diagnose dyslexia it is important to consider whether reading performance was compared to non-verbal IQ only, verbal and non-verbal IQ or a composite score. When SRD or dyslexia has been diagnosed on the basis of comparison with non-verbal IQ only, many of these readers may have unrecognised concomitant language difficulties, which may be further contributing to the observed reading difficulty. These readers may then, in fact be less-skilled readers. In another study where a ‘poor’ reader group is inclusive of dyslexic readers, the findings may be skewed by poor naming ability, a feature of dyslexia, but not be representative of less-skilled reader performance. While the criteria mentioned above are most common across studies, other criteria are sometimes used and when provided, an explanation of the selection criteria will be given. There is a great need for clarity of definition in order for research to form valid conclusions about the experimental groups studied.

2.2 Models for Word Reading

There are three models of reading used in the reading research which will now be reviewed:

1) the PALPA model of word reading, incorporating the dual-route model of visual word recognition
2) phonological mediation, incorporating the bimodal interactive model of word recognition
3) the connectionist model of reading

2.2.1 The PALPA model

In the related field of cognitive neuropsychology one assumption is that a set of cognitive processes, or modules, are responsible for a certain cognitive function e.g. word naming or object recognition. Each module is susceptible to disorder or injury, while other modules in the process remain intact. This is known as the modularity hypothesis. Under this hypothesis, particular functions of the brain may be affected while others are unaffected. A reading model that is based on this assumption is a modular system (Ellis & Young, 1988).

The psycholinguistic assessment of language processing in aphasia (PALPA) and corresponding PALPA model were designed in 1996 by Kay, Lesser and Coltheart. For the purposes of this research, the PALPA model provides a modular system for print processing (reading words silently and aloud), language processing and object/picture naming, allowing all three aspects to be discussed within one model. The marriage of speech input processing and print input processing is of great value for this research on the relationship between auditory processing and reading ability, best explained by Gough and Tunmer (1986) as: “once the printed matter is decoded, the reader applies to the text exactly the same mechanisms which he or she would bring to bear on its spoken equivalent” (p.9).

Further, the PALPA recognises the importance of phonological working memory, separated into the *phonological input buffer* and the *phonological input lexicon*, for input processing. For comparative models see Ellis and Young (1988), Patterson and Shewell (1987) and Swanson (1987).

The PALPA model is displayed in Figure 1. Each box in the model (such as Semantic System) represents a repository of information as well as a locus of information processing. The arrows between the boxes represent the direction of information flow (Kay, Lesser & Coltheart, 1996) and in this way processing becomes staccaded with each box i.e. the processing from the previous locus of processing being added to the next.

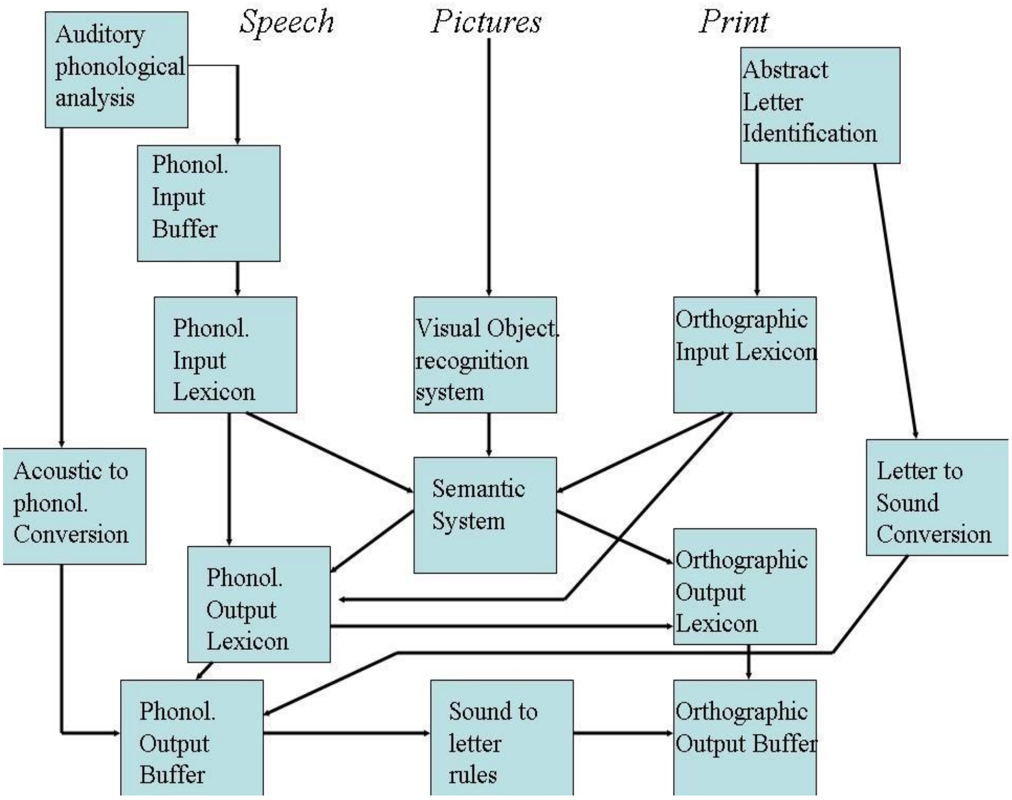


FIGURE 1:
The PALPA model (adapted from Kay, Lesser and Coltheart, 1996)

Spoken language processing is represented on the left hand side and written language processing on the right hand side both accessing the same semantic system. In the middle section familiar objects and pictures are visually recognised before their meaning is activated in the semantic system. The route on the far left of the PALPA model (Figure 1) shows that it is also possible for spoken words to be repeated without accessing meaning via *acoustic-phonological conversion*.

Comprehension of spoken utterances by the semantic system necessitates both *auditory phonological analysis* and access to the long-term repository of familiar words, the *phonological input lexicon* via the *phonological input buffer*. Following arrival of an auditory signal at the sensory register (the ear) *auditory phonological analysis* involves:

a) extraction of intensity, frequency and duration features
b) analysis of slow cues e.g. pitch, intonation, stress
c) analysis of fast cues e.g. manner, voicing, place of articulation

(Medwetsky, 2002a)

Between *auditory phonological analysis* and the *phonological input lexicon* lies the *phonological input buffer (PIB).* The *PIB* enables the temporary storage of the sounds or phonemes of words that have been identified before the whole word has been recognised. This temporary storage system can be considered similar to or a subsystem of phonological working memory (PWM). The main difference between the two is that isolated sounds or phonemes are stored in the PIB whereas whole words, phrases or sentences can be stored in PWM. The concept of PWM is critical to the present study and will be reviewed in section 2.3 on the central executive.

2.2.2 The Dual-Route Model of Single Word Reading

In relation to reading, the PALPA model represents a dual-route model of word reading composed of a lexical (orthographic) and sub-lexical (phonological) route. The dual-route reading model described by Coltheart (1978), as displayed in Figure 2, is consistent with the PALPA model. The lexical route is employed in the naming of recognised whole words whereas the sublexical route is employed in the reading of unfamiliar regular words and nonwords. The written word *may* be visually recognised, converted to a phonological map and read aloud, with or without semantic access, as shown on the model. This is sometimes referred to as ‘direct visual access’. Single word reading via the lexical route requires orthographic processing of the written word via the *orthographic input lexicon.* This is the long-term repository of recognised written words. The letters of the word presented are recognised by a system of *abstract letter identification* and then the word is compared to known words in the lexicon to determine familiarity. A real word, once recognised, is linked to its meaning or semantic representation in the long-term repository, the *semantic system.* To say the word, the phonological representation held in the *phonological output lexicon* is accessed. The information flows to a temporary storage system referred to as the *phonological output buffer* which ensures that the motor plan for the word to be executed has been accurately planned in sequence.

An unfamiliar word or nonword must be processed via the sub-lexical route. This will still require a degree of *abstract letter identification* to distinguish the word from similar real words e.g. ‘chack’ vs. ‘shack’. Letter-to-sound conversion (or grapho-phonemic conversion) is applied to construct the phonological representation of ‘chack’. Unfamiliar real words also access the sub-lexical route and will usually be regularised such that the word ‘some’ may be read as rhyming with ‘home’ or the word ‘even’ may be read as rhyming with ‘seven’. The product of letter-sound conversion flows to the *phonological output buffer* prior to execution. The phonological output is spoken when reading aloud and is therefore subject to *auditory phonological analysis* prior to arriving at the *PIB.* When reading silently, the phonological representation can flow directly to the *PIB.*

Good phonological awareness skills are a prerequisite for success via the sublexical route. Semantic associations for real words are activated by the partially or wholly completed phonological representations (Bishop, 2002). For instance, while reading the sentence ‘The boy was changed into a pig by the wizard”, the written word ‘wizard’ may be visually unfamiliar (yet linguistically familiar) to the reader who commences decoding aloud using the sublexical route, sounding ‘w-i-z’, but once ‘wiz’ has been achieved, the partial phonological representation enters as speech input, as per the PALPA model, then activates known phonological representations to assist retrieval of ‘wizard’.

Coltheart et al. (1994) proposed that phonological activation occurs in a ‘cascade’, activating different semantic representations until a good ‘fit’ with context is achieved. Obviously, the rate at which this occurs will have an impact on reading proficiency, in turn affecting working memory processes and ultimately, reading comprehension. This proposal seems to provide a plausible response to the quandary of how a two-stage orthography-to-phonology-to-meaning conversion is able to occur so rapidly in proficient readers. When reading a sentence or passage the available linguistic cues prior to an unfamiliar word in the text may also assist retrieval (or any picture cues if available). Good readers progress from reading real words via the sublexical route to the lexical route more rapidly when there exists a strong underpinning of phonological awareness and efficient grapho-phonemic correspondence (Coltheart & Leahy, 1996; Snowling, 2000a).

It is possible for orthographic rules (letter-sound correspondences) to be accessed at a high level of proficiency in some individuals so that almost any word can be presented and read aloud without accessing meaning. This represents a secondary sub-lexical route as shown on the far right in Figure 1 where a word is processed by *letter-to-sound rules* then the *phonological output buffer,* but is not fed back through the semantic system. This assumes that (output) phonological representations are not mandatorily linked to semantic representations.

Finally, there are two output systems in the PALPA model: spoken output and written output. Coltheart, Rastle, Perry, Langdon and Ziegler (2001) report on studies investigating brain injury that provide evidence that some individuals are unable to speak yet can still write while others can speak but are unable to write (Basso, Taborelli & Vignolo, 1978) following injury. Therefore spoken output and written output are separate output systems.

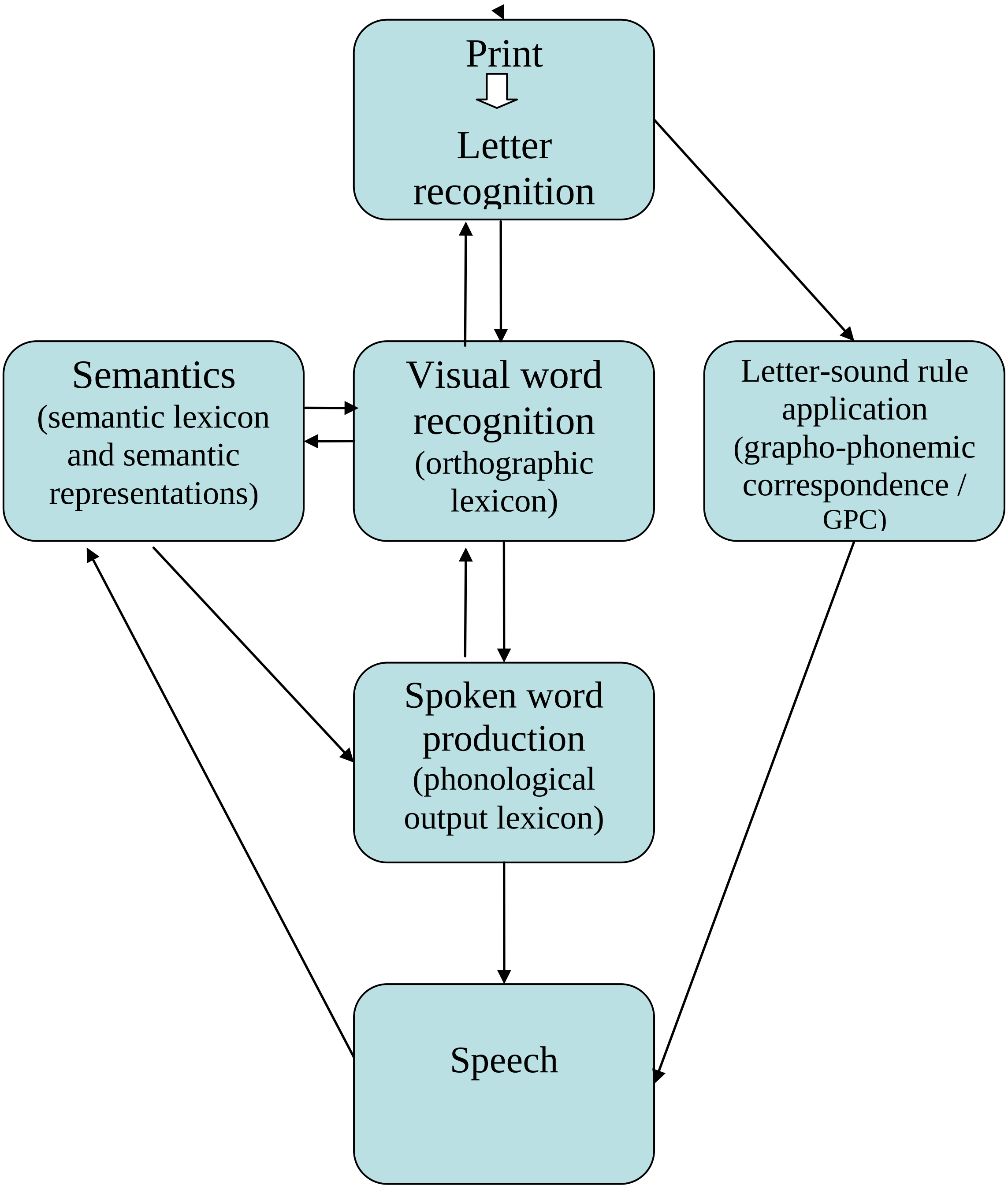


FIGURE 2:
The dual route model of single word reading. The lexical route is on the left and the non-lexical or sublexical route is on the right (adapted from Coltheart et al., 2001; Rastle, 2007).

Familiar high frequency words are read most rapidly via the lexical route. Unfamiliar phonetically regular words requiring decoding via the sublexical route will be read more slowly. Unfamiliar low frequency words that do not have a regular letter-sound correspondence (irregular words) set up a conflict between the lexical and sublexical reading route and will take longer to read, often unsuccessfully in younger readers (Howard & Best, 1996).

As mentioned previously, the major difference between the PALPA model and the dual-route model is the flow between the orthographic (input) lexicon and the phonological (input) lexicon. Later versions of the dual-route model have bidirectional flow between the orthographic lexicon and the phonological lexicon, allowing for phonological mediation of the written word (Rastle, 2007). Both the orthographic input lexicon and phonological output lexicon activate the semantic system. Orthographic information activates stored lexical phonological maps and in turn, these phonological maps assist retrieval of lexical orthographic maps prior to the word being read aloud. Evidence for this bidirectional flow of information was substantiated by Van Orden (1987) and replicated by Coltheart et al. (1994) who found homophone effects in reading whereby university graduates took longer to decide whether pseudo-homophones e.g. ‘burd’ were real words compared to non-words ‘deeg’. In addition, a greater number of errors occurred for the pseudo-homophones than the nonwords. It also took subjects longer to decide whether written homophones were real words (lexical decision task) e.g. ‘meat’ compared to non-homophones e.g. ‘game’. Van Orden (1987) also showed that spelling errors which violate the phonology of the word are more easily detected than errors which do not violate the phonology. Both homophone effects produced in the study provide strong evidence of the phonological mediation of written words prior to semantic access. Frost and Ziegler (2007) summarised that the past 20 years of research has “established that the recovery of phonological structure is a mandatory phase of print processing” (p.108).

The dual-route model for single word reading does not account for the entire mechanisms of text reading. Semantic access at the word level is optional. However, in normal text reading the semantic branch of the lexical route is more actively employed because the meaning of preceding words has been activated and succeeding words may be predictable from the syntactic and semantic cues contained within the phrase or sentence. For instance, while reading the sentence ‘They went to the pool to go for a swim’, the child may already have activated an expectation of the word ‘swim’ and so the written word is readily recognised. Some caution must be taken into account though: Predicting a word takes longer than visually recognizing word (in good readers) and it is estimated that about one in ten words can be accurately predicted from context alone (Gough & Tunmer, 1986).

Coltheart et al. (2001) proposed the dual-route cascaded model (DRC) to account for the influence of the lexical route upon the sublexical route. This influence has been demonstrated in a number of studies whereby the decoding of the nonword e.g. ‘louch’ is influenced towards a rhyme with ‘couch’ when it is preceded by the word ‘sofa’, but is rhymed with ‘touch’ when preceded by the word ‘feel’ (Rosson, 1983). Other examples which demonstrate lexical influence include delayed response times by university students (n = 12) for reading nonwords that have an inconsistent production in real words e.g. ‘heaf’ (could rhyme with ‘deaf’ or ‘leaf’) took 646 milliseconds compared to consistent productions e.g. ‘hean’ which took 617 milliseconds. The same effect was found with real irregular inconsistent words e.g. ‘deaf’ took 618 milliseconds whereas the regular consistent word ‘dean’ took 598 milliseconds to read aloud (Glushko, 1979). Coltheart argues therefore, that in order to evaluate the letter-sound system in isolation, nonwords would need to have little or no shared orthography with real words. This can be difficult to manipulate, but certainly tests of nonword reading vary in their ability to achieve this aim.

The DRC allows for information from the letter-sound route to be fed back to both the phonological input lexicon and the lexical semantic route (as in the PALPA model), acknowledging that during reading the phonology of a word can be assembled partly from sublexical and partly from lexical influences. A ‘gating’ technique was used by Bruno et al. (2007) who concluded that dyslexic readers have reduced access to phonological codes. The ‘gating’ technique verbally provides increasing segments of a word and participants are asked to predict the whole word. Dyslexic readers (n = 23; 9-14 years) performed more poorly than controls (n = 23; 8-14 years) on this task. Snowling (2000) reported on earlier studies that do not concur with these findings in the dyslexic population and one explanation may be that the dyslexic group in Bruno’s study was defined by the severity of reading delay where a definition of SRD may have been more appropriate. Essentially, the previous example of a child decoding the first three sounds of the word ‘wizard’ sublexically but then producing the entire word as a result of lexical influences i.e. ‘w-i-z’-> ‘wizard’ demonstrates gating. The assembly of the word from both lexical and sublexical influences represents the ‘weak phonological hypothesis’, first proposed by Frost (1995). The contrasting position is the ‘strong phonological hypothesis’ whereby reading always involves sublexical phoneme conversion or phonological mediation. Under the strong phonological hypothesis phonological mediation occurs even in highly competent readers though they may lack the introspection to be aware of the mediation process. The strongest evidence against the strong phonological hypothesis comes from the reading pattern of phonological dyslexia whereby the reading of nonwords is impaired, yet reading of irregular words is unimpaired indicating a direct lexical visual route (Coltheart et al., 2001).

Coltheart (2001) devised a computational model of the DRC that contained three routes: the lexical semantic route, lexical non-semantic route and grapheme-phoneme correspondence (GPC) route. In the computational model there are 7,981 orthographic lexical units and 7,131 phonological (output) lexicon units, developed for English. The computational DRC model demonstrated that reading was influenced by phonology but was deemed consistent with the weak phonological hypothesis (Coltheart et al., 2001).

Criticisms of the dual-route model are three-fold. Firstly, the model is criticised for the implication in the model that sub-lexical access is too slow to be efficient and secondly, that the sublexical route does not access semantics (Luo, 1996) until after the phonology is assembled. Thirdly, it is debated whether direct visual access can actually occur without phonological mediation (Van Orden, 1991; Frost, 1995; Luo, 1996). The assumption that the phonological route is only accessed when the lexical route fails or is slow has been brought into question. As explained in the upcoming section, it is now considered that orthographic input is phonologically mediated prior to semantic access (Frost & Ziegler, 2007).

2.2.3. Phonological Mediation

Brysbaert, Grondelaers and Ratinckx (2000) investigated the strong vs. weak phonological hypothesis. Taking advantage of a feature of Dutch verbs, in which verbs of different tenses have a different orthography but shared phonology, they determined that verb tense in sentences could be determined from orthography alone by university students (n = 42). They concluded that orthography does assist word identification especially when the phonology is ambiguous e.g. homophones. They acknowledge that this does not infer that there is a direct orthography-semantic route.

Frost (1995) examined whether written Hebrew words that had ambiguous pronunciations (presented without the diacritics to indicate the vowel sounds) were produced more slowly by undergraduate students than unambiguous words for both low and high frequency words. High frequency words were named significantly faster than low frequency words and ambiguous pronunciations were produced significantly more slowly than unambiguous pronunciations as expected. Frost's second experiment determined that when ambiguity was removed, frequency remained the only effect on naming latency. The third experiment was designed to show whether ambiguity of pronunciation affected lexical decision (deciding between real word or nonword). The participants did not need to pronounce the words, only press a 'yes' or 'no' button. If written words are not phonologically mediated there should be no effect of phonological ambiguity. Ambiguity was not significant with again, only word frequency being significant for real words. Frost (1995) concluded that the findings provided evidence that written words are phonologically mediated only when a phonological representation is required, either silently or aloud.

The finding that real word lexical items that have only one lexical match were read more slowly when the diacritics for pronunciation were absent provides evidence that phonology is not retrieved in lexical units, but by letter-to-phoneme conversions that are then assembled into a lexical unit. This process is referred to as assembled phonology or the phonological recoding hypothesis. Phonological recoding occurs when any non-phonological stimulus is converted to speech sounds. Most commonly the stimuli are objects, pictures or letters. Addressed phonology (or the visual access hypothesis) is the opposing hypothesis whereby lexical units are retrieved as a whole (Folk, 1999; Luo, 1996). The conciliatory view is taken in the connectionist model whereby lexical access occurs via both direct visual access and by phonological recoding (see section 2.2.4).

Some researchers argue that even words directly accessed are still phonologically mediated (Van Orden, 1987). In Van Orden's (1987) experiment undergraduate students were given a category label and then asked to decide whether homophonic heterographs belonged to that category e.g.'fish' -> 'sole-soul' or 'flower' -> 'rows-rose'. Van Orden (1987) demonstrated a significant lag time in the homophone condition and more errors occurred on the homophones than the spelling foils, indicating that phonological mediation of the word must have occurred. Later experiments using larger sample groups were able to replicate the homophonic effect, extending it to include nonwords e.g. 'clothing -> 'sute-suit', providing strong evidence for the role of phonological mediation in reading. Coltheart et al. (1994) also showed that homophonic heterographs (e.g. 'jeap' -> 'vehicle' category) were accepted significantly more often as belonging to a semantic category than incorrect non-homophonic items with orthographic similarity to target items (e.g. 'steek' -> 'meat' category) by first-year psychology students. The homophonic heterographs were also rejected significantly more slowly. The conclusion drawn from the above findings is that phonological mediation activates semantic access more strongly than orthographic input and therefore phonological mediation plays a critical role in reading comprehension.

Luo (1996) also adopted the strong phonological hypothesis and argued that phonological mediation is the sole route to the internal lexicon and its associated semantics. Luo’s (1996) experiment used word pairs e.g. lion-bare, lion-bean and then asked college students (n = 24) which word in the pair was more strongly related to a third word e.g. ‘wolf’. When the initial word pair contained a homophone of a semantically related word, error rates were significantly higher and responses were significantly delayed. Further, when there was a delay before the third word was presented, the interference effect was reduced, indicating that the confusion between phonology and orthography had been resolved prior to the presentation of the third word. Luo’s findings conflict with the dual-route model which places the sublexical route requiring grapheme-to-phoneme conversion as being slow and cumbersome for fluent reading. Luo concluded that phonological mediation occurs prior to and assists lexical-semantic access. As a consequence of these findings, Luo offers the revised dual-route model shown in Figure 3. Under this model, the two routes remain, but the main revision represents the phonological route as faster, indicated by darker arrows on the model. The phonological information is then checked against the orthographic information for accuracy. It may be important to consider the age of the reader when interpreting the revised dual-route model. Younger or less competent decoders may shift weight to orthographic access, resulting in whole word substitutions for unfamiliar words.

While there is no spoken auditory input during the silent reading task, written words are phonologically mediated during reading and therefore subject to processing by the *phonological input buffer*. The *phonological input buffer* holds the phonemes in sequence to allow lexical decision making (real word vs. nonword), then the *phonological input lexicon* which contains a store of all known words in phonological form recognises the real word (if known) prior to accessing the *semantic system*. The phonological code of the word in the *phonological input lexicon*, activates the semantic code/s in the *semantic system*. When the task requires repeating the word, the *phonological output lexicon* is organised, and the phonological map is temporarily held and analysed by the *phonological output buffer* prior to execution.

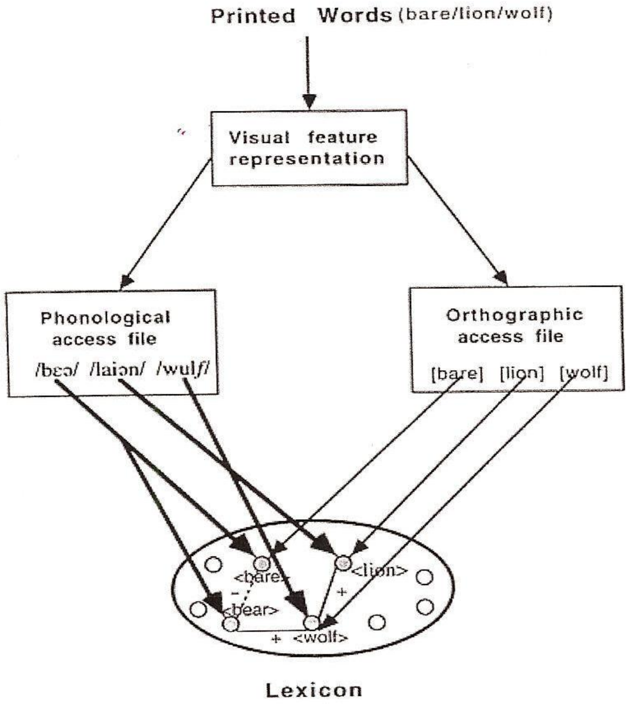


FIGURE 3: A revised dual-route model of single word reading (Luo, 1996)[3]

---

[3] Luo, C. (1996) Figure 2 “A revised dual-route model of lexical access in reading printed words” p.36. Reprinted with permission, American Psychological Association.

Folk (1999) supported this view and found evidence that orthography is phonologically mediated during silent reading. Folk's (1999) experiments monitored eye movements (gaze duration) as university undergraduates (n-44) silently read homophonic heterographs (e.g. ate/eight) embedded in text. As expected, readers had significantly longer gaze duration (283 msec vs. 263 msec) on the homophonic heterographs than controls even when the semantics were unambiguous. In the first experiment the context was semantically neutral and in the second experiment the context was semantically biased. This is an important finding as it follows that phonological mediation and phonological working memory are just as important in silent reading as when reading aloud. Folk (1999) concluded that "phonological codes play an important role in meaning activation" (p.904) in a study of silent reading processes.

Ferrand and Grainger (1994) investigated orthographic and phonological priming of target words and found that orthographic information is activated first, peaking at about 30 milliseconds after exposure then dropping, with phonological activation lagging by about another 30 milliseconds. Phonology then continues to facilitate word recognition and semantic activation. The interpretation was that both orthography and phonology make an independent contribution to word identification, but this evidence strongly suggests that a direct visual-to-semantic route is unlikely. They developed a lesser known model, the bi-modal interactive activation (BIA) model of word recognition which postulates that the orthographic input lexicon and phonological input lexicon work together to activate semantic representations, increasing the chance of reaching threshold for semantic activation (Grainger & Ferrand, 1996). This contrasts with models that have independent routes, each vying to activate semantics first. The basis of the BIA model is that orthographic knowledge is being mapped onto the established phonology-to-semantics pathway that exists for spoken language. This overlay of written input into an existing phonological pathway would explain why semantic activation may take place mid-word i.e. the phonology is assembled prior to the whole word being identified. Under capacity theory, the respective contribution of each input lexicon (orthographic and phonological) would be dependent upon the demands being placed on the other.

Put together, the research indicates that phonological mediation plays an important role in reading, and may be vital for semantic access for comprehension. If *all* written words are phonologically mediated in the reading task, the acquisition of a strong phonological input lexicon with stable phonological representations must be critical to achievement of reading proficiency.

2.2.4 Connectionist Models of Reading

The connectionist model described by Seidenberg (1993) draws together the orthographic and phonological routes for word recognition and is therefore a hybrid model, sometimes referred to as a parallel distributed processing model. The orthography of the word is converted to a phonological representation either directly or with the added utilisation of letter-sound conversion. The connectionist model gives greater weight to the phonological route than the dual-route model and views phonological mediation as the faster, more direct route to reading. In Seidenberg’s research a computational program was devised. Firstly the program, known as SM89, was trained to produce correct pronunciations of a set of monosyllabic words. The orthographic information for a word was entered as itself and its ‘neighbours’. Snowling (2000a) provides the example that ‘net’ would be entered as ‘-ne, net, et-’ (p.83). The phonological information entered for this word would be ‘nasal-vowel-stop’. Information about frequency and consistency of letters (orthography) to sounds (phonology) was then programmed. By adding weight to correct pronunciations and error scores to incorrect pronunciations, the program effectively ‘learns’ from experience how to pronounce the words. Reading was achieved by reinforced association of letter strings with phonological representations. Theoretically, given all the necessary information, a high rate of reading success should ensue. Seidenberg (1993) achieved a computational model which could correctly pronounce 97% of 2,897 real words and 85% of nonwords presented based on the programmed information. A later version of the model was more successful with the reading of nonwords by applying more information about how pronunciations alter in different phonological contexts. The words included both phonetically regular and irregular words. It was observed that inconsistent words e.g. ‘gave’ vs. ‘have’ had a longer naming latency under the model in the same way that readers require slightly more time to read these words aloud (Seidenberg, 1993). Under this model, successful performance was affected by the ‘computational capacity’ available. They found that sublexical processing needed to cascade onto the succeeding levels in order to continuously process incoming information. Seidenberg proposed that deficits in an individual’s computational capacity could be the source of individual variability in reading performance.

A major criticism of Seidenberg’s model (1993) was levelled at the absence of reference to semantics. Yet there is little argument that the purpose of reading is to access meaning. Interestingly, during the evolution of the program it became particularly important to provide more information to assist decoding of irregular (or quasiregular) words for success to occur. A later model proposed by Plaut, McClelland, Seidenberg and Patterson (1996) attempted to correct for this by adding semantic input to the phonological input. With the addition of semantics, the system more closely resembled the normal reading process. In the natural educational context, orthographic and phonological associations are assisted by semantics during book reading from the earliest levels, with support from pictorial information or linguistic prediction. Plaut et al. (1996) found that phonological processes continued to be used for reading regular words, despite semantic input. However, with input from semantics, phonological processes were less important for reading irregular words.

Plaut et al. (1996) hypothesized that reading is actually a ‘division of labour’ between firstly, mapping phonological information onto orthography and secondly, a semantic process of mapping meaning to both the orthographic and phonological representations. Plaut et al. were also able to replicate developmental phonological dyslexia by ‘lesioning’ the phonological input in their connectionist model and developmental surface dyslexia by ‘lesioning’ the semantic input. They described the former performed as if the sublexical phonological route had been ‘turned down’ and the latter as if the orthographic route had been ‘turned down’.

Put simply, the connectionist model represents reading as a triangular process drawing upon orthographic, phonological and semantic information with constantly shifting weight between the three inputs (Frost & Ziegler, 2007). It is important at this juncture to consider the effects of weakness in any one of these three areas, the consequence of which may add disproportionate reliance on the other areas during the reading process. The computerised connectionist models continue to evolve. As yet, the connectionist model is unable to fully account for the complexity of semantic representation and the visual aspects of the reading process.

2.3 The Central Executive

Superimposed on any information processing model is the notion of the *central executive* or *executive function.* The role of the central executive includes the allocation of three processes required for the task: attention, cognition and working memory (Swanson, 1987). Input processing competes for allocation of these three elements, which will each be reviewed in the forthcoming section. It is important to be aware that these variables have an impact on performance of any task, and can be extremely difficult to eliminate as artefacts in research exploring a specific modality such as working memory. For instance, to be certain that an individual has PWM difficulty, information regarding the individual's attentional abilities, cognitive ability and language abilities should also be gathered (Cacace & McFarland, 1998).

2.3.1 Attention

The central executive performs the function of information 'gate-keeping'. It decides upon the relevancy of information, allocating attention to relevant information while inhibiting irrelevant information received from the environment. Attention is understood to play an important role in short term memory by filtering out irrelevant information and focussing attention to the task of recall. In turn, the performance of short-term memory affects PWM performance and the transfer of information to long-term memory (Cowan, 2001). Research on attention dysfunction, including *f*MRI studies has consistently found frontal lobe abnormality. The precise interaction between attention and memory is still a subject of ongoing research, but with the converging weight of data, it has been concluded that there is currently no evidence that auditory processing causes difficulties in attention (Cacace & McFarland, 1998). Attention and auditory processing are not interchangeable processes.

Performance on any task can also be affected by levels of vigilance (arousal) and motivation. Optimal performance is achieved at moderate arousal levels and performance is adversely affected when arousal is too high or too low (Medwetsky, 2006). Performance is enhanced by higher levels of motivation and adversely affected when motivation is too low. While these factors are acknowledged they are not the subject of the present research.

2.3.1.1 Attention and reading

Children with learning disability consistently show difficulties on tasks of attention with the effect becoming weaker with increasing age (Copeland & Wisniewski, 1981). However, it has been demonstrated that deficits of attention are separate from deficits of reading ability (Felton & Wood, 1989). It is thought that the co-morbidity occurs because children with attention deficits will have secondary learning difficulties and children with learning disabilities will experience attentional difficulties due to repeated experiences of failure and associated anxiety (August & Garfinkel, 1990; Pennington, Grossier & Welsh, 1993).

Co-morbidity of attention deficit disorders and reading difficulty has also been reported in the literature. For instance, Felton and Wood (1989) concluded that while a few studies have been suggestive of attentional difficulties in some readers with specific reading disability, particularly with the allocation of attention (selective attention) in complex tasks, there have also been alternative explanations for these observations such as lack of automaticity with sub-components of the task. Felton and Wood (1989) classified readers according to their reading errors as being normal, nonspecific, dysphonetic (phonological errors), dyseidetic (visual errors) or mixed. Readers diagnosed with attention deficits were found to shift error categories over time, suggesting unpredictability in reading performance. For example, a reader with attention deficits may decode using phonetic strategies on one occasion, but not on another. They concluded that attention deficits and reading disability were unrelated conditions.

To investigate the high occurrence of reading comprehension difficulties in the population with diagnosed ADHD, Ghelani, Sidhu, Jain and Tannock (2004) studied four groups of adolescents (n = 96); ADHD, reading disability (RD), ADHD with RD and a control group. The purpose of this study was to highlight the challenges facing a student with both ADHD and RD. Interestingly, the ADHD group, without RD, had ‘subtle’ difficulties with reading accuracy, reading rate and silent reading comprehension, though all results were within the average range. In addition, the ADHD group with RD had similar difficulties with reading accuracy and rate but greater difficulty with silent reading comprehension. The researchers suggest that the poor result on the silent reading comprehension task in this group indicated a difficulty sustaining attention on a self-paced task. It has also been proposed that reading comprehension deficits may be the result of poor inhibition of irrelevant information resulting in interference with working memory processes, again in accordance with structural capacity theory (Goff, 2004).

Interest in the effects of inhibition processes led Gernsbacher, Varner and Faust (1990) to conclude that poor comprehenders are inefficient at suppressing irrelevant information, at rejecting inappropriate meanings of ambiguous words and incorrect forms of homophones. A study by De Beni et al. (1998) looked at the frequency with which poor comprehenders provided irrelevant information in the reading span test. The participants were asked to recall the last word read in a sentence. They found that poor comprehenders exhibited a higher number of intrusions i.e. words contained in the sentence but not the final word. The findings suggest that comprehension does not rely solely upon linguistic ability and most likely involves central executive function (including attention) even when cognition and intelligence are controlled (Gernsbacher et al., 1990; De Beni et al., 1998; De Beni & Palladino, 2000).

Waring, Prior, Sanson and Smart (1996) were able to establish that both attention and behaviour were significant factors in whether children performing below one standard deviation from the mean in Year 2 ‘recovered’ from this reading difficulty by Year 6. ‘Recovery’ was assumed to have occurred when the student scored within one standard deviation on reading tests in Year 6. The Rutter Child Behaviour Questionnaire that was used includes scales of hostileaggression, anxious-fearful and hyperactive-distractible behaviours. The questionnaire was administered in Years 2, 4 and 6. Of these factors, those which significantly correlated with persistent low reading ability were hyperactivity (inefficient attention allocation to the task) at Year 4 and at Year 6 both hostile-aggressive and anxious-fearful behaviours. Interestingly, significant differences between 'recovered' readers and those with persistent reading difficulty were found only for boys in the sample. The recovery process was impeded by significant behaviour problems in boys only, suggesting that there may be gender differences in the 'mechanisms' of recovery from reading difficulties.

There is very little support for the notion that reading difficulties can be *explained* by attentional difficulties. For instance, there is no evidence that readers with dyslexia have difficulty sustaining attention on other cognitively demanding tasks (Pennington et al., 1993; Farmer & Klein, 1995). It is also valuable to note that there is little evidence to suggest phonological deficits based on the reading errors made by individuals diagnosed with attention deficit disorder. Difficulty reading irregular words is more common (Felton & Wood, 1989). Nevertheless co-morbidity of attentional difficulties with reading difficulties may be an important consideration for programming intervention as the child may be facing additional challenges to those of a child with reading difficulty alone.

2.3.2 Phonological Working Memory

The concept of phonological working memory (PWM) is vital to the understanding of vocabulary acquisition and comprehension. PWM was first described by Baddeley and Hitch (1974) as: "…a limited capacity system allowing the temporary storage and manipulation of information necessary for such complex tasks as comprehension, learning and reasoning” (quoted in Baddeley, 2000, p. 418).

The current model of PWM is composed of the following components:

1) episodic buffer
2) phonological loop
3) visuo-spatial sketchpad

(Baddeley, 2000)

The episodic buffer was proposed by Baddeley (2000) as the system responsible for integrating, binding and temporarily storing multimodal information from the phonological loop, visuo-spatial sketchpad with existing information from long term memory. Studies to date indicate that the prefrontal and parietal regions are involved in the episodic buffer system (Gathercole, Pickering, Ambridge & Wearing, 2004). The other two systems, the phonological loop and the visuo-spatial sketchpad are considered ‘slave’ systems within working memory as depicted in Figure 4. These systems are designed to temporarily retain incoming information (Gathercole, Pickering, Ambridge et al., 2004). The phonological loop is assumed to be located in the left parietal and anterior temporal lobes while the visuo-spatial sketchpad is assumed to be located in the parieto-occipital region and inferior frontal area (Gathercole, Pickering, Ambridge et al., 2004).

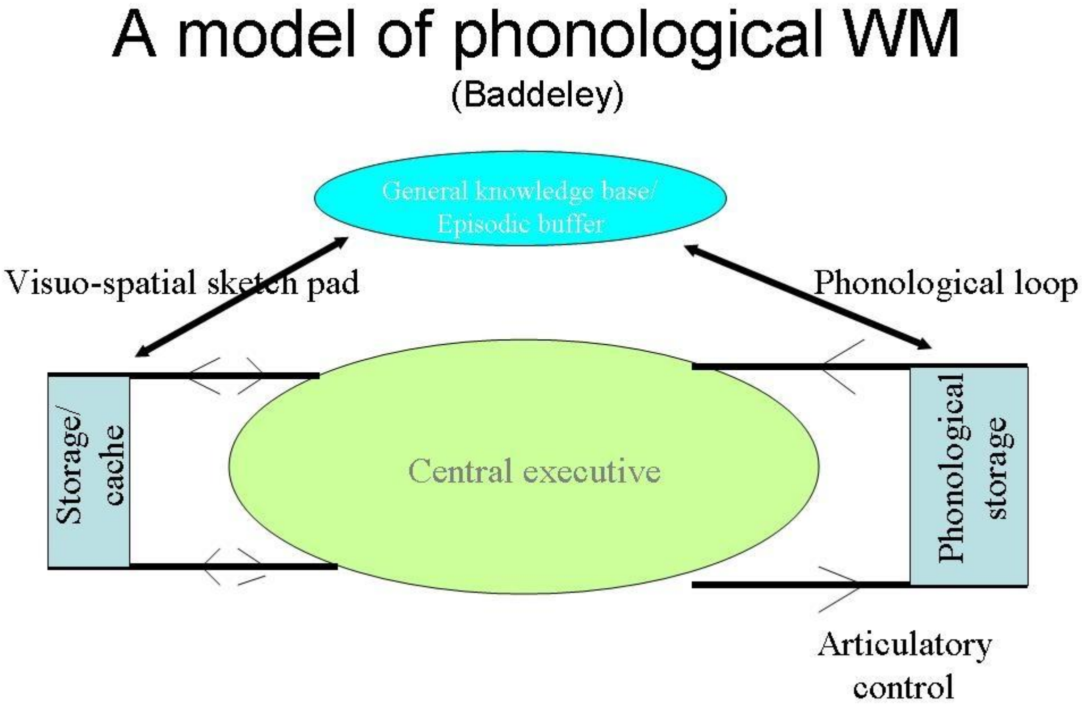


FIGURE 4:
A model of phonological working memory (adapted from Baddeley, 2000)

The phonological loop has two components; short-term phonological storage and an articulatory rehearsal process. When speech is perceived it enters the short-term phonological storage, sometimes called echoic memory. In adults the storage capacity is considered to be equivalent to about two seconds after which time the auditory trace fades unless attended to and rehearsed by the phonological loop. Two seconds equates with about eight syllables, but the duration and phonological complexity of the syllables is more relevant than the number; any number of words or syllables that can be repeated within 2 seconds equates with average short-term memory capacity (Gathercole & Baddeley, 1993; Baddeley & Hitch, 1994; Service, 1998). Therefore, there is a time-based component to short-term and working memory in addition to factors of load and complexity (Towse, Hitch & Hutton, 2000). Towse et al. (2000) defines load as the energy required to process the information after the first item. Load is increased by complexity which absorbs the available time.

The phonological loop is considered to be capable of operating independently from cognitive involvement (Gathercole & Baddeley, 1993) when required. Acting independently, the phonological loop serves to allow verbal repetition of numbers, words or short sentences without necessarily accessing semantic connections from long term memory. The information will then be lost. This skill is also necessary for repetition of nonwords with no existing semantic links. Rehearsal by subvocalising or speaking aloud the verbal material slows the rate of fade, decay and loss of the information of the auditory information over time (Gathercole & Baddeley, 1993). Rehearsal is thought to serve at least three purposes: to assist storage of auditory input into long-term memory, to keep phonemic information active during the reading process and to assist in the assembly and production of speech output (Jones, Macken & Nicholls, 2004). The phonological loop is only able to perform one function at a time. For instance, we may be able to perceive a speaker while processing reading input, but be unable to recall the words spoken.

During verbal auditory short-term memory tasks the temporary trace in the phonological store is available to PWM but will not enter long-term storage without further processing. One view describes short-term memory tasks such as digit (number) recall as “tasks that tap the storage capacities of the working memory system but impose only minimal demands on processing” (Gathercole, 2007, p. 758). Another view is that short-term memory tasks are under the domain of attention (Cowan, 2001).

PWM acts on the phonological and linguistic information from short-term memory via the rehearsal process prior to entry into long-term storage. Auditory input can be visually or semantically encoded while in working memory, prior to storage in LTM. The episodic buffer assists in this process by integrating the phonological information with existing (semantic) knowledge and information from the visuo-spatial sketchpad (and possibly other sensory information) to prepare it for storage in long-term memory. The role of the episodic buffer is to make 'sense' of the information so that it is stored appropriately. Consequently, individuals who make efficient use of existing associations and relationships, such as numerical patterns may well perform better on tests of short-term memory such as digit span. The phonological information must be encoded and maintained in the correct sequence, without loss of integrity in order to be transferred to long-term memory in an undegraded form (Gathercole, 1995). The central executive is responsible for allocating attention to the episodic buffer so that the phonological, semantic and syntactic information received is relayed to higher cognitive levels. The phonological loop is then available to take in new phonological information from the short-term phonological store.

Individuals with impaired PWM have shown significant impairments in learning new words and therefore it has been suggested that the phonological loop plays an important functional role in holding information prior to new word learning and is therefore critical for language *acquisition* (Baddeley & Hitch, 1994). Baddeley, Gathercole and Papagno (1998) reviewed the literature and concluded that there was indeed good evidence that the phonological loop plays a 'crucial' role in the learning of new phonological representations.

Three effects known to enhance the capacity of the phonological loop in serial word recall tasks: high frequency items, items within the same semantic category and real words (compared to nonwords) can be explained by the ease of activating existing information from long term memory into PWM. High frequency items are thought to have higher resting levels of activation (priming) than low frequency items prior to the task. Items within the same semantic category also activate associated items via spreading activation, making associated items easier to retrieve (Gathercole & Baddeley, 1993). Real words have an existing phonological and semantic representation, resulting in more rapid rehearsal and repetition than nonwords.

The consistent co-occurrence of poor PWM and low vocabulary performance would seem to substantiate this conclusion (Gathercole & Baddeley, 1993). While still under debate, there is good evidence that vocabulary acquisition is an important function and purpose of PWM and the phonological loop. The capacity of the phonological loop in serial word recall tasks and learning of nonwords is known to be influenced by the following three effects:

a) word length effect; fewer longer words can be repeated than shorter words in the same time span (Baddeley, Thomson & Buchanan, 1975);
b) phonological similarity effect; phonologically similar words result in fewer correct items recalled in the correct order (Conrad & Hull, 1964; Mann, Liberman & Shaywitz, 1980);
c) articulatory suppression effect; spoken repetition of an irrelevant distractor keeps the phonological loop occupied, resulting in decreased recall of the relevant target words in correct order (Murray, 1967).

Word length effect is attributed to the inability to rehearse longer words as rapidly as shorter words. The articulatory suppression effect is also thought to disrupt rehearsal in the phonological loop and has also been shown to impair the ability to detect rhyme. Interestingly, articulatory suppression does not interfere with reading (Gathercole & Baddeley, 1993). However, the phonological similarity effect is understood to occur in the phonological store as the result of difficulty separating words that are phonologically similar (Baddeley et al., 1998). The phonological similarity effect has been typically found in children over the age of 8 years only whereas the word length effect is present from 4 years with verbally presented material, but over 7 years for pictured material (Baddeley & Hitch, 1994), corresponding with the onset of verbal rehearsal.

An additional consideration is that poor quality input available to the phonological loop may also result in confusion in the phonological store and consequently have an impact on capacity: a signal integrity effect. It has been found that working memory capacity correlates with speed of processing (Kyllonen & Christal, 1990). A signal integrity effect would be expected to reduce speed (and accuracy) of access to the phonetic code, exacerbate the phonological similarity effect and thus, constrain efficiency of PWM. Baddeley et al. (1998) stated that nonword repetition performance “is constrained by the quality of phonological representation of the just-spoken unfamiliar item” (p.168). Gathercole (2007) summarised the process of learning new words as follows:

> …initial encounters with the phonological forms of novel words are represented briefly in the short-term store…these representations form the basis for the gradual process of abstracting

> a stable specification of the sound structure across repeated presentations. Conditions which impair the quality of the temporary phonological representation, such as a storage system with a low functional capacity due to either noisy or degraded representations, will reduce the efficiency of the process of abstraction, leading to slow rates of learning. (p.763)

Indeed, poor readers (mean age: 8;2) in the late stages of their second year of schooling made more errors on recall of both rhyming and non-rhyming items (presented visually and auditorily in different trials) than good readers (mean age: 8;0), but surprisingly there was a smaller, non-significant difference in performance between the two types i.e. a reduced phonological similarity effect compared to the good readers (Shankweiler, Liberman, Mark, Fowler & Fischer, 1979). The poor readers were also less affected by a 15 second delayed recall of the items than the good readers. The researchers concluded that rehearsal processes were less effective in the poor readers as a consequence of slower access to the phonetic code and/or a degraded phonological representation. They propose that less effective rehearsal reduces confusion between the items compared to the more rapid rehearsal rate of the good readers. That is, poor readers experience overall discrimination difficulty with both types of test items, but performance is not greatly hampered by the presence of rhyming items. An alternative explanation is that the high number of errors made by poor readers on the non-rhyming items does not leave a sufficient margin for an increase in errors on rhyming items to show a significant degree of difference between the stimulus types.

McNeil and Johnston (2004) investigated the word length and phonological similarity effects in visual tasks, based on the model proposed by Gathercole and Baddeley whereby the phonological loop actively converts and maintains phonological information derived from visual input (e.g. pictures, letters or words). The aim of the study was to investigate the role of the phonological loop in reading. McNeil and Johnston (2004) investigated poor readers (mean age: 12;0) compared to reading-age matched controls (mean age: 7;6) . Using picture stimuli, they expected poorer recall of phonologically similar words due to confusion caused by decay of distinctive phonological information (phonological similarity effect) and poorer recall of longer words due to limitations of short-term memory capacity used in rehearsal (word length effect) for both controls and poor readers. In the picture presentation task, both effects were present in controls but the phonological similarity effect was significantly reduced in poor readers and the word length effect was absent in poor readers. They concluded that poor readers prefer to make greater use of visual rather than phonological storage of information, when the task does not demand phonological recoding. This finding suggests that poor readers may avoid phonological decoding when reading, preferring a visual approach.

PWM is understood to play a pivotal role in the development of phonological representations of sounds, syllables and words in long-term memory (Gathercole & Baddeley, 1990; Baddeley et al., 1998). The auditory phonological information is encoded to form a phonological representation or ‘map’ of the word. Stable phonological representations are necessary for efficient speech perception. The representations are composed of all aspects of sounds within the acoustic speech signal. The central executive must act upon that information in order for long-term storage to occur. When the input temporarily held in PWM is poor, Gathercole and Baddeley (1993) have described the resultant phonological representations as being in a "noisy and unreliable form, or a form in which the serial order of the phonemes is not strongly represented or their phonological representation may decay very rapidly" (p.71). Poor representation has implications for vocabulary acquisition and the quality of what can be achieved by the cognitive and linguistic processes acting upon that representation, organised by the central executive.

While the components of PWM are present at birth, short-term memory capacity does not asymptote to adult levels of performance until the early teens. One of the reasons that short-term memory capabilities increase with age is thought to be proportional to the increased rate of articulatory rehearsal that occurs between 4 and 13 years of age and generally increased operating efficiency of the components of working memory (Gathercole et al., 1992). However, it could be argued that it is the rate of matching incoming input to existing phonological representations rather than rate of articulatory rehearsal that affects short-term memory performance (Brady et al., 1983; Elbro, Borstrøm & Petersen, 1998). Poor quality phonological input and poor quality representations would slow processing in PWM, regardless of articulatory rehearsal potential.

An impairment of PWM results in difficulties repeating unfamiliar phonological sequences in the form of nonwords and making associations between familiar words (Gathercole et al., 1992). Gathercole and Baddeley devised a nonword repetition test as a measure of phonological loop dysfunction. The ability to repeat nonwords is analogous to the process of encountering a novel vocabulary item and therefore supports the important role of the phonological loop in the acquisition of new vocabulary.

Using *f*MRI, hypoactivation of the brain areas involved in language, attention and working memory was found in adolescents with language impairments (Jones, Plante, Tomblin & Weismer, 2005). Even though the sample was small (n = 8), they found less activation in the left inferior frontal gyrus, left pre-central sulcus and left parietal cortex during PWM tasks in individuals with language impairment compared to controls (n = 8). The researchers concluded that deficits in attention and PWM play a role in constraining language development, including vocabulary. PWM may also play a role in long-term storage of semantic representations of new vocabulary. A weak phonological loop results in rapid loss of phonological information for long-term storage. This would have a detrimental impact on the accuracy and stability of the *phonological representations* of spoken words and the amount of information available for long-term *semantic representations* (Gathercole & Baddeley, 1993; Baddeley & Hitch, 1994).

It has been proposed that during comprehension tasks, PWM may allow the necessary time for phonological matching, syntactic parsing and semantic searching and association. However, a range of studies investigating the effect of poor PWM on comprehension have yielded mixed results, ranging from significant to nonexistent effects (Baddeley & Hitch, 1974; Stothard & Hulme, 1992). Such variable findings regarding the effect of poor PWM upon comprehension *may* be due to individual differences in the strategies employed to assist retention of meaning. This may include other sensory information such as visual, tactile or even emotional information about words and concepts. For example, hearing the sentence ‘We went to the pet shop and bought a puppy’ may elicit an image of a small fluffy dog and arouse protective instincts, thus assisting comprehension of the sentence, without necessarily being able to recall the sentence verbatim. At the very least, it can be said that the phonological loop and PWM may be a back-up system to assist comprehension, especially for large amounts of information or in sentences with distance between connected components e.g. “The child (Subject) who was playing in the park (Relative Clause) had a red ball (Verb + Object related to Subject)”

In summary, evidence indicates that PWM plays a vital role in vocabulary acquisition. Impairments in PWM due to either poor quality input in the short-term phonological storage or inefficient phonological loop function may result in unstable phonological representations or diminished semantic representations. Evidence suggests PWM plays a lesser role in comprehension, having a greater impact when larger amounts of information are to be recalled or when sentences require recall of related components that are separated by distance.

2.3.2.1 Phonological working memory and reading

An increasing number of studies support the relationship between PWM and reading. Gathercole, Pickering, Knight, and Stegmann (2004) showed a reliable correlation between tests of working memory and performance on national literacy and numeracy testing in the UK at both 7 and 14 years of age. At 7 years of age correlations between digit span, listening recall and nonword repetition scores to English results ranged from 0.36 to 0.49. At 14 years of age the correlations were maintained but were lower, ranging from 0.32 to 0.35 (Gathercole, Pickering, Knight et al., 2004).

In another large-scale UK study of 3,189 students aged 5 to 11 years, Alloway et al. (2009) determined that about 10% had PWM difficulties. Further, 67 % of the students with low PWM (n = 308) scored greater than one standard deviation below the mean on standard scores of reading ability, and about half were currently accessing special education assistance. The researchers concluded that low PWM should be considered a high risk factor for academic underachievement. A relationship between PWM and literacy (both reading accuracy and reading comprehension) has been reported in many other studies (Mann et al., 1980; Katz, Shankweiler & Liberman, 1981; Brady et al., 1983; Cain, Oakhill & Bryant, 2004). For instance, Cain, Oakhill and Bryant (2004) concluded that “working memory capacity explains unique variance in reading comprehension between the ages of 8-11 years” p.40. PWM was also found to be a significant factor in the recovery of students labelled as reading disabled in Year 2 whose reading accuracy fell within the average range in Year 6 (Waring et al., 1996). Despite increasing support for the existence of a relationship between

PWM and reading, the exact nature of the relationship is yet to be fully understood.

Bishop (2001) investigated whether poor nonword repetition could be attributed to a single cause. She found evidence that poor nonword repetition was heritable and was a risk factor for literacy difficulty, as measured on a word reading test in Study One of multiple birth siblings aged 7 to 16 years (n = 116) with speech and language difficulties. However, in Study Two nonword repetition ability was unrelated to nonword reading ability in a large general population sample (n = 200). Bishop concluded that any nonword reading difficulties in this sample were more likely to be of environmental causation. Causal environmental factors explored included parental occupation, parental education and family size, with the former two factors being significantly associated with nonword reading ability. Maternal educational status has previously been found to be one of the most important environmental predictors of reading acquisition and is presumed to be associated with the linguistic environment provided in the home (Snowling, 2000b). Bishop concluded that genetic factors are only implicated in literacy outcomes when language, nonword repetition and literacy difficulties are all evident.

Mann et al., (1980) found that PWM was significantly poorer in a group of poor readers compared to good readers on a (spoken) serial word recall task. Results for the poor readers were significantly more affected by the introduction of noise than for the good readers. This indicates a susceptibility to auditory interference when processing verbal input which would place demands on PWM capacity. However, results between the reader groups were not significant for non-speech sounds. After numerous studies in the area, Shankweiler (1989) stated it is the challenge to determine how PWM depends upon the integrity of phonological processing and by implication, what causes breakdown in efficient phonological processing that potentially leads to reading breakdown.

2.3.3 Cognition and Intelligence

As well as allocating attention and inhibiting irrelevant stimuli, the central executive integrates information from various regions of the brain for the purposes of reasoning and regulating verbal and motor behaviour. The co-ordination of attention, perception, long-tem memory and PWM is otherwise known as cognition. Tests of intelligence aim to evaluate cognitive ability, with examinees attaining an intellectual quotient or IQ score as a measure of this ability compared to chronological age.

Strong correlations between PWM and IQ are often reported, but the interaction is not fully understood (Baddeley & Hitch, 1994). A good example of the separation between PWM and IQ has been provided by Gathercole (2007). Children aged 5 to 6 years were asked to perform simple one, two or three-step instructions. Their performance was strongly correlated with working memory performance but not to non-verbal IQ scores. The conclusion was that PWM is a system that supports comprehension and cognition, but should not be confused as *being* either comprehension or intellectual ability. It would seem logical that the more readily auditory input can be matched to existing phonological representations, the faster the phonological loop can take in new material, thus increasing capacity available for cognition. In order to achieve this, the input needs to be of good quality, matched to stable phonological representations.

2.3.3.1 IQ scores and reading

A common fallacy is that the individual with reading difficulty has a concomitant intellectual deficiency yet this contention has consistently not been borne out (Siegel, 1988; Bishop & Adams, 1990; Muter, Hulme, Snowling & Taylor, 1997). Children of average intellectual ability are assumed to be able to acquire reading skills more readily however, correlations of reading ability to full scale IQ scores are generally weak, as previously mentioned (Siegel, 1993). This has been reported by Stanovich (1986) to be between 0.3 and 0.5 in the early years of schooling. Snowling (2000) reported that IQ scores explain no greater than 16% of the variance in reading scores.

Measures such as phonological awareness, auditory short-term memory and listening comprehension correlate more highly with reading ability than IQ (Bishop & Adams, 1990; Stanovich, 1991; Muter et al., 1997). For instance, Muter *et al*. (1997) found, using regression analysis, that phoneme segmentation significantly predicted reading at the end of the first year at school whereas full-scale IQ scores did not. However, IQ scores predicted segmentation ability. Muter *et al*. (1997) postulated that IQ may facilitate phonological awareness in the early years and may again become important in the later years of schooling when comprehension of more complex concepts is required. Waring et al. (1996) demonstrated that IQ scores were moderately correlated with reading outcomes in readers who had been identified as reading disabled in Year 2, but were average readers in Year 6. Similarly, Stanovich (1986) has reported that the correlations between intelligence and reading achievement are higher in adults than in children, suggesting that either intelligence plays a role in reading outcomes or that reading ability has an impact on IQ test performance. In support of the latter contention, Stanovich (1986) reported that verbal IQ scores have been observed to decline in some poor readers. It is also interesting to note that Siegel (1988) reports that reading ability can predict both phonological skills and short-term memory more reliably than IQ scores.

Bishop and Adams (1990) showed that reading comprehension was significantly poorer in a group of 83 children with a history of language delay (mean age: 8;6) compared to a control group. When scores were adjusted relative to verbal and non-verbal IQ scores, the poorer reading comprehension scores could not be explained by non-verbal IQ. Instead, verbal IQ scores have been found to be more predictive of reading performance (Siegel, 1988; McDougall & Ellis, 1994; 1995) and in particular reading comprehension (Stothard & Hulme, 1995). Stothard and Hulme (1995) found that readers with good decoding ability but poor comprehension scored significantly poorer on two verbal IQ tasks, Vocabulary and Similarities subtests, on the Wechsler Intelligence Scales for Children -Revised (WISC-R) (Wechsler, 1974) compared to the two control groups (chronological age-matched and comprehension age-matched), but there was no significant difference on the two non-verbal tasks, Block Design and Object Assembly subtests. Oakhill, Cain and Bryant (2003) also found a significant correlation between reading comprehension on the Neale Analysis of

Reading Ability -Revised (Neale, 1989) and verbal IQ scores on the WISC-R (r = 0.417).

Stanovich (1986) reported that in reading research, reading-disabled groups are generally 6 to 9 points lower on IQ scores than matched controls, despite falling within the average range. However, when Siegel (1988) classified children into four IQ score bands, namely IQ <80, IQ80-90, IQ91-109, IQ≥110), as many poor readers fell into each band as good readers. In the same study, language skills and short-term memory ability were poorer in children aged 7 to 16 years with a reading disability (n = 250) compared to normal readers (n = 719). Her results were replicated by Share, McGee and Silva (1989). A longitudinal study by Alloway (2009) concluded that working memory at initial assessment was a better predictor of learning outcomes two years later than IQ scores. Siegel (1988) made the bold conclusion that IQ scores were 'irrelevant' in the diagnosis of reading disability.

Vellutino, Scanlon and Lyon (2000) supported the findings of Siegel (1988) and also Fletcher, Shaywitz, Shankweiler et al. (1994), stating that: "they provide strong evidence that measures of language and language based skills are better predictors of reading ability than are IQ scores" (p.225). Stanovich (1991) too, has argued that a standardised measure of listening comprehension would be a better predictor of reading ability than either verbal or non-verbal measures of IQ. However, the measurement of oral language skills, particularly listening comprehension, as a predictor of reading ability, presents a conundrum for the population with auditory processing deficits who are characterised by difficulty with listening comprehension that may bear little relationship to reading ability.

Certainly the use of full-scale IQ scores to predict reading ability would be a misconception of the relationship. Higher correlations between verbal IQ and reading ability have been achieved, but it is generally held that verbal IQ scores alone may underestimate cognitive ability (McDougall & Ellis, 1994). McGuiness (2005) agreed and further suggested that it is likely that a higher non-verbal IQ could compensate for weaker language abilities in reading comprehension tasks. In summary it would seem that full scale IQ scores are weakly correlated to reading ability, verbal IQ scores may be a better predictor of reading ability and non-verbal IQ scores may be a better predictor of long-term reading outcomes. The conclusion that can be presently drawn from the reading research is that it is more fruitful to investigate the subskills of reading e.g. phonological awareness, language and memory than to make predictions about reading from IQ scores. This does not discount the value of further investigation of the relationship between intellectual ability and reading performance.

2.4 Auditory Processing

The detection and perception of environmental sounds developed for the purposes of survival and it is speculated that speech initially developed for the same reason; as a means to communicate danger to others (Bryson, 1990). Speech did not shape the development of an auditory system and instead, speech had to be shaped by the parameters of the existing system. Therefore speech relies upon changing frequency represented by different firing rates, sound contours and bursts of sound in the same way as environmental sounds do (Eggermont, 2001). These three elements are sometimes referred to as the information-bearing elements. When the sounds form meaningful speech, the information-bearing elements must be preserved and analysed for comparison with existing phonological representations. The success of a multitude of comparisons determines the phonology of the language that is ultimately perceived, interpreted and understood. Evidence provided by recipients of cochlear implants suggests that temporal information is more important than spectral information for the identification of phonemes (Eggermont, 2001).

Auditory processing skills have been implicated in the development of listening skills, attention, memory, language, word-finding, reading and spelling and there have been many attempts to arrive at a clear definition of auditory processing. One broader definition states that auditory processing is ‘the serial and parallel processing of the auditory system responsible for auditory attention, detection and identification of auditory signals, decoding of the neural message, as well as storage and retrieval of auditory-related information’ (Wilson, Heine & Harvey, 2004). Phillips (2002) prefers ‘the resolution, differentiation and identification’ of auditory percepts from auditory input (p.255). A simpler operational definition is also offered by Katz who states that auditory processing is “the use we make of the auditory signal” (Katz, Stecker & Henderson, 1992, p. 4). The aim of auditory processing is always to achieve maximal speed of processing with minimal error (Boothroyd, 1997). Auditory processing is represented by the *auditory phonological analysis* module on the PALPA model in Figure 1.

Auditory processing encompasses the process by which the spoken input is analysed in preparation for linguistic analysis. Speech input is a continuous acoustic stream of sounds consisting of different frequencies and intensities, arriving in rapid sequence and with brief gaps within the signal. The stream of sounds must be perceived by the listener, separated from other acoustic input, integrated from both ears, phonologically analysed in sequence and semantically linked in order to gain meaning from that signal. The process can be explained by the depth-of-storage model which views information as being processed from 'shallow' to 'deeper' levels (Butler, 1983). Using a depth-of-storage model the levels of processing linguistic information in bottom-up order include:

- sensation of auditory input;
- perception of the auditory input;
- integration of the auditory information;
- phonemic-phonologic analysis;
- morpho-syntactic analysis;
- semantic analysis;
- suprasegmental analysis

(Massaro, 1975; Jerger, Martin & Jerger, 1987; Swanson, 1987; Bellis, 2003).

An explanation of the above levels follows:

1. sensation of auditory input- at this level the auditory signal is detected by the peripheral auditory system. This can be measured by tests of peripheral hearing and is *not* auditory processing. For instance, the sounds of talking may be detected by the sensory system;
2. perception of auditory input – auditory processing commences at this level. Features of the auditory neural signal are conveyed in terms of frequency (pitch), amplitude and temporal aspects e.g. sequence, gaps in sound, predominantly in the auditory cortex (or Heschl's gyrus) in the

temporal lobe. For instance, the sounds of talking may be perceived as speech;

3. integration of the auditory information – at this level the stream of target speech information must be separated from any co-occurring speech or sounds, the target information received by both ears must be organised into a coherent whole in readiness for linguistic processing in the relevant areas of the left cortex;
4. phonemic-phonologic analysis- the phonemes (sounds) of speech are compared to stored information based on the *patterns* of sound received regarding onset of sound, bursts of intensity within sounds (formants), voicing, duration of sounds, manner of sound production and taking into account the rules of word construction of the language being used. Perceptual units or ‘chunks’ of information are matched with existing phonological representations for recognition, thought to be accessed primarily in Broca’s area in the left frontal lobe, with association areas in the superior and middle temporal region (Gazzaniga, Ivry & Mangun, 2002). This is the lowest level of linguistic analysis;
5. morpho-syntactic analysis – the utterance received in the left cortex at the linguistic region known as Wernicke’s area located in the parietal lobe is analysed in terms of its grammatical structure to determine the tense of the utterance (past tense, present tense or future aspect), whether it is in the negative or positive, active or passive etc.;
6. semantic analysis – at the same location the intended *meaning* of the concepts and content words in the utterance is activated by comparing the words and concepts to existing semantic representation;

7. suprasegmental analysis – further auditory information may be analysed that provides information about the speaker's purpose of the communication i.e. a comment, an instruction, a demand, a criticism, praise, conveyed in the stress, rhythm, rate or intonation patterns. This pragmatic and prosodic analysis may also provide the listener with further information about the speaker's emotion, intentions or expectation of the listener.

Auditory features of speech available for speech perception include:

1) fundamental frequency – pitch of individual's voice;
2) harmonic structure - bands of energy around the fundamental frequency represent the acoustic contours that assist sound identification;
3) formant structure – peaks and troughs of energy due to vibration of the vocal tract assist sound identification;
4) onset and offset information – the commencement and cessation of acoustic input or voicing within the signal assist sound identification;
5) the speech envelope – the low frequency slow temporal information in the speech signal that provides cues to prosody e.g. stress, duration.

Responses to auditory input (speech and non-speech) can be measured by auditory brainstem responses (ABR), cortical evoked potentials measured using electroencephalography (EEG), functional Magnetic Resonance Imagery (*f*MRI) and positron emission tomography (PET). The technology has permitted researchers to study processing of speech harmonics, including the onset and offset of voicing at the level of brainstem. Harmonic structure conveys the intention and emotional state of the speaker. Processing of voicing onsets and offsets has been found to be abnormal in language-disabled and reading-disabled individuals (Banai et al., 2009), providing evidence of a link between low level auditory processing and higher level tasks such as language processing and reading. Speech processing acts independently of speaker characteristics so that sounds can be identified irrespective of the speaker. It is still only speculation that a phonemotopic map of sounds exists at the cortical level, but it is known that tonotopic representation of frequencies exists (Abrams & Kraus, 2009).

Both speech and non-speech input activate the auditory cortices, but the rapid frequency changes of speech also activate the left superior temporal sulcus, the area responsible for linguistic processing whereas non-speech leads to greater activation in the right auditory cortex, suggesting greater spectral analysis. Temporal features of the speech envelope are also processed at the cortical level. For instance, auditory evoked potentials indicate that phase-locking (matching the neurological response to the stimulus) to the syllable /ka/ occurs at 40ms into the stimulus but perception does not occur until 60ms suggesting that the acoustics are firstly perceived then confirmed linguistically 20ms later (Abrams & Kraus, 2009). It is important to note that auditory evoked potentials are an indirect measure of phonological and linguistic analysis.

Although much of the research has focussed on individual sounds and consonant-vowel speech segments, there is dissent about what constitutes a meaningful perceptual unit. Some argue the perceptual unit is the phoneme unit or the consonant-vowel unit while others argue it is the syllable unit or whole word unit. However, it is possible that the size of the unit is not at issue, but rather the meaningfulness of the unit. For instance, the phoneme /æ/ pronounced as the allophone /ə/, may be sufficient for linguistically recognising the indefinite article ‘a’ as in ‘a dog’ in context.

It is important to delineate what represents auditory processing and what represents linguistic processing in the information processing model. At the level of perception and integration of acoustic information, the spectral features (frequency, intensity, timing) of the incoming sounds are analysed and represent auditory processing. Individual speech sounds, or phonemes, are identified based on this information as a ‘marriage’ between auditory and linguistic processing. This is the highest level of auditory processing. At the point where these sounds are then categorised into a perceptual unit for linguistic analysis, linguistic processing has occurred. Proponents of larger perceptual units or top-down processing take the view that a bottom-up approach cannot account for variability in individual speakers (speaking rate, fundamental frequency, emotional state, dialect, intensity) nor situations of ambient noise that degrade the input and yet the listener is able to nonetheless understand the input (Pisoni & Levi, 2007). Therefore, the accepted view is that bottom-up and top-down processing occur simultaneously, shifting the weight of processing in either direction according to the acoustic and linguistic demands of the situation.

2.4.1 Auditory Processing Disorder (APD)

In 1954 Helmer Myklebust emphasized the importance of investigating auditory function beyond peripheral hearing in children with communication disorders. He used the term *auditory imperception* to describe children who were having difficulty with how they hear, rather than what they hear (Bellis, 2003). This was a revolutionary proposal at the time. Other terms used to describe this condition have included central deafness, central hearing loss, auditory agnosia, dysacusis, nonsensory hearing loss and obscure auditory dysfunction. Currently the term APD or (central) APD is used (CAPD) (Wilson et al., 2004). The use of the term '*central* APD' is controversial as it has been argued that the degree of peripheral involvement at the level of the cochlea (such as the tonotopic organization of the outer hair cells for registering frequency input) is the commencement of auditory processing (Moore, 2007).

A disorder of auditory processing manifests as difficulty with listening despite normal hearing and intelligence, particularly in the presence of competing noise and/or competing speech (Keith, 1986; Smoski, Brunt & Tannahill, 1992a). APD has been broadly defined by the American Speech and Language Hearing Association (ASHA) as a "difficulty in the efficiency and effectiveness by which the central nervous system (CNS) utilizes auditory information" (2005). That is, APD is a breakdown of efficient information processing at the level of auditory integration or perception, which has an impact upon storage and output. Attempts to determine a primary deficit in APD have led to four areas being put forward as potential candidates:

1) Auditory discrimination: difficulty discriminating speech. Assessments may include tests of word repetition, sound localisation, gap detection, frequency discrimination or intensity discrimination;

2) Auditory figure-ground: difficulty discriminating target sounds (eg. speech) in the presence of competing sounds. This may be due to deficits in sound localisation, discrimination of speech sounds or auditory closure. Assessments may include detecting target sounds or speech against noise or competing speech;
3) Temporal resolution: difficulty localising sound or determining the onsets, gaps and changes within sounds or a series of sounds across time. Assessments may include separation of competing information delivered to each ear, integration of different information delivered to each ear or temporal order judgement of pitch patterns;
4) Auditory memory: difficulty with short-term recall for auditory information. Assessments may include repetition of a number series (digit span), nonwords, a word series or sentences.

(Wilson et al., 2004)

Individuals with APD commonly have difficulty processing the speech signal, resulting in mis-hearing or misunderstanding of the linguistic input. Listening fatigue is common, often resulting in inattentive behaviour. Individuals with APD typically exhibit difficulty with following instructions and processing new information. Diagnosis of APD in a school-age child is usually made after the child has been referred for assessment of auditory processing abilities by an audiologist due to concerns about academic under-achievement relative to cognitive ability, difficulty following instructions or poor listening behaviours in the classroom. Social difficulties are also common in children with APD who often find it difficult to follow conversations, respond appropriately and remember information about others.

A markedly reduced ability to perceive speech in the presence of background noise is one of the most commonly reported patterns in individuals with APD (Jerger & Musiek, 2000; Wilson et al., 2004). Some researchers would argue that this *is* the primary deficit in APD (Jerger et al., 1987). Listening is not simply difficult in noisy situations, but speech is often so difficult to perceive that the individual (or parent thereof) may seek professional confirmation of whether a disorder exists. Persons referred for assessment of auditory processing abilities commonly report “being uncertain about what they hear, having difficulty listening in the presence of background noise, having difficulty following oral instructions and having difficulty understanding rapid or degraded speech” (Jerger & Musiek, 2000, p. 467).

The ability to hear against background noise requires being able to detect the target signal as separate from other sounds. The simultaneous presentation of a conflicting speaker can affect the perception of sound e.g. when the sound /b/ is presented simultaneously with /g/ then the phoneme /d/ is likely to be perceived even in listeners with an intact auditory system (Green & Norrix, 1997). Binaural hearing assists the separation of speakers from other speakers or ambient noise by determining different arrival times (spatial filtering) and different amplitudes and frequencies of all sounds in the environment (spectral filtering) (Eggermont, 2001). Abnormal brainstem responses have been linked to susceptibility to noise and also reduced sensitivity to acoustic changes (Wible, Nicol & Kraus, 2005). When the information received by both ears cannot be separated or integrated efficiently, the ability to separate the target from the noise will be disrupted. This is sometimes described as a low tolerance for noise.

Comprehensive assessment of auditory processing incorporates past and present reports from parents and teachers plus ideally, behavioural observations in order to make assumptions about the accuracy and efficiency of functional information processing for that individual prior to formal testing. Audiological testing is then used to test and deliberately challenge the auditory system by reducing redundancy of the speech input by filtering the auditory input, or by applying background noise, or by presenting information to each ear separately or by presenting non-speech information for processing such as clicks or tones. A disorder is most commonly determined via audiological testing whereby failure on two or more tests of auditory processing in a test battery constitutes an APD.

The prevalence of APD is not well documented, but has been estimated to affect between 2-3% of school age students (Chermak & Musiek, 1997). However, when Domitz and Schow (2000) applied a criterion of failure of ≥ 1 standard deviation below the mean on any *one* test within an auditory processing battery, 21% of 81 third grade students would have been classified as having an auditory processing difficulty. The likelihood of a false positive diagnosis based on performance on one test in a battery has been heavily criticised by Cacace and McFarland (1998). For instance, in a study by Musiek, Geurink and Kietel (1982) seven auditory processing tests were administered. The probability alone of failing one of seven tests at a cut-off of the lowest 5% was greater than 30% and at a cut-off of the lowest 10% was 52%. At a criterion of ≥2 standard deviations below the mean 14% of the students would classify as having an APD in the Domitz and Schow study (2000). It was deemed that the application of 1 standard deviation criterion over-identified students with APD, extension to 3 standard deviations from the mean was statistically impractical and that a point of 2 standard deviations or greater below the mean best corresponded to the level of concern about low performance in client groups. Geographic variation of prevalence is assumed, based on variations in risk factors across ethnicity and culture. Identified risk factors include prematurity, low birthweight, maternal drug or alcohol abuse and chronic otitis media (Chermak & Musiek, 1997).

Auditory processing and APD are controversial topics. In recent times the diagnosis of APD has been challenged by linguists, psychologists, educators and the medical profession on the basis that auditory processing cannot easily be distinguished from linguistic, cognitive, attention or memory ability during evaluation. The linguistic argument, put simply, states that speech is processed via top-down cognitive or linguistic means, without reliance upon bottom-up processing (Duchan & Katz, 1983; Sternberg & Powell, 1983). The input is combined with existing knowledge to create meaning. This may be successful when predictable language is delivered in ideal acoustic conditions, but less so when the information is not predictable. When the signal is degraded or competing background noise is present, this approach becomes even less successful because the accessibility of bottom-up information has been reduced. Even individuals with normal auditory processing abilities find listening more difficult in these situations. In the case of APD, the central auditory nervous system (CANS) itself further degrades the incoming signal (Wilson et al., 2004).

It is important to determine whether APD is distinct from a general disorder of attention, memory, language or cognition even though auditory-specificity is a difficult goal. In theory, an individual who has met the diagnostic criteria for an APD, should also be able to demonstrate normal performance on non-auditory tasks, such as pure visual tasks, including visual memory, otherwise it is likely that a more generalised memory or attention deficit exists. While short-term memory difficulties for digits, letters and pictures (requiring phonological transformation), words and sentences have been found in poor readers, deficits in the visual recall of abstract shapes or unfamiliar lettering have not (Vellutino, Fletcher, Snowling & Scanlon, 2004). This indicates that the short-term memory deficits in poor readers are specific to the verbal domain i.e. verbal recall or *naming* of visual stimuli. This reflects a difficulty retrieving phonological information, for both real words and nonwords. The question is whether the difficulty lies with memory storage, capacity or central executive management of retrieval (McNeil & Johnston, 2004).

In APD research, measures of intellectual ability and language ability are vital for synthesis with the audiological findings. It is important to note that language deficits can occur in the absence of auditory deficits and vice-versa, but it is the co-occurrence of auditory and linguistic deficits that is of interest, both clinically and to this study. As previously stated, other factors often attributed to the central executive such as motivation or attention are more difficult to control in research (Cacace & McFarland, 1998). Cacace and McFarland proposed that a diagnosis of APD may arise when in fact it is one disorder co-existing with other disorders of information-processing or alternatively, a disorder due to non-auditory factors such as attention or motivation.

In children, developmental causes such as neuromorphological disorders in the left hemisphere or the sulcus of the corpus callosum have been proposed as causative of APD as have maturational delays of the CANS and neurodegenerative disorders, disease or insults to the CANS (Musiek & Lamb, 1994; Chermak & Musiek, 1997). Neuromorphological abnormalities within the CANS include polymicrogyri and heterotopias and are suspected to be responsible for at about 65-70% of APD diagnoses. Maturational delays of the auditory system account for about 25-30% of APD diagnoses. Only about 5% of APD diagnoses are thought to be attributed to neurologic disorders, diseases or lesions as a result of injury in the left hemisphere or auditory regions of the corpus callosum (Wilson et al., 2004). Brain imaging technology is currently being used to investigate the accuracy of these estimates. It is not surprising that a common site of lesion has not yet been found for all individuals diagnosed with APD given the complexity of the CANS. Whereas genetic influences have been found for related conditions including hearing impairment, language impairment and dyslexia the heritability of APD is presently unconfirmed (Moore, 2007). Despite the challenges to its existence, auditory processing and APD continue to be investigated and documented. Auditory pathways exist and neural pathways are vulnerable to abnormality and so it follows that APD must exist (Wilson et al., 2004).

2.4.2 Development of Auditory Processing

The anatomical components of the auditory system are present at birth. However, further maturation takes place for up to 20 years (Johnson, Nicol & Kraus, 2005). Myelination of the auditory nerve and brainstem in the first 6 months of life ensures that the ability of infants to detect frequencies and intensity levels approximates adult performance (Boothroyd, 1997). Frequency discrimination typically matures between 6 and 9 years of age (Thompson, Cranford & Hoyer, 1999) though there is now evidence that the developmental period may be longer, and possibly that discrimination of higher frequencies matures prior to discrimination of lower frequencies (Heath, Hogben & Clark, 1999; Fischer & Hartnegg, 2004). Discriminating speech against background noise continues to develop until about 12 years of age as axons mature in the auditory cortex.

The majority of the linguistic information presented to the right ear crosses to the left hemisphere for processing whereas linguistic information delivered to the left ear crosses to the right hemisphere but must then return to the left hemisphere via the corpus callosum for linguistic processing. Therefore, the stronger (more efficient) ear is opposite to the dominant hemisphere for speech and language, referred to as the right ear advantage. Around 5 to 6 years of age, the right ear advantage has been observed, but may be present earlier (Boothroyd, 1997). Until about 11 years of age, linguistic information delivered to the right ear is processed more efficiently than information delivered to the left ear (Pinheiro & Musiek, 1985a). However, if left ear processing is even poorer than expected given a right ear advantage or continues to be poor past the time of expected maturation, this indicates delayed or abnormal myelination and has been associated with reading difficulties (Lamm & Epstein, 1997).

Data on electrophysiological response times to sound input has shown that myelination of the corpus callosum continues until 15 to 20 years of age, making it the last structure in the auditory pathway to mature (Boothroyd, 1997; Medwetsky, 2002a). Once mature, the corpus callosum constitutes a horizontal fibre bundle containing more than 300-400 fibres and is approximately 6.5 cm long and 0.5-1.0 cm thick. The fibres of the corpus callosum connect analogous areas across the hemispheres and are critical for interhemispheric transfer of information (Love & Webb, 1986; Boothroyd, 1997). Auditory information passes through the section of the corpus callosum known as the sulcus.

It is commonly stated that auditory processing abilities reach maturity at around 12 years of age. This belief has possibly emanated from the normative data available on auditory processing assessments for children in the 7 to 12 year old age band. However, there is now strong evidence to suggest that auditory processing skills continue to improve with maturity and at least into adolescence. Using tests of frequency discrimination, intensity discrimination, gap detection and temporal order judgement Fischer and Hartnegg (2004) were able to demonstrate that maturation of these auditory skills continues to occur up to 16 to 18 years of age. Temporal order judgement (TOJ) is considered to incorporate both temporal resolution and auditory sequencing skills. The skills selected by Fischer and Hartnegg were chosen because they represent the auditory characteristics of speech sounds i.e. rapidly changing frequency and intensity, brief gaps and the requirement to preserve the sequence of sounds in order for the integrity of the words and phrases to be understood. Performance of the 682 participants (250 dyslexic subjects and 432 controls) aged 7 to 22 years were grouped into 4 age bands (7-8 years, 9-10 years, 11-13 years, 14-17 years). Frequency discrimination and temporal order judgement performance were strongly correlated in controls and dyslexic subjects. Frequency discrimination and gap detection were not significantly correlated. There is presently insufficient data surrounding the exact developmental course of the ability to determine temporal gaps in sound (Boothroyd, 1997). The lack of correlation between frequency discrimination and gap detection supports the theory that these auditory processing skills represent different auditory functions.

The notion that auditory processing skills develop at different rates was further supported in Fischer and Hartnegg’s (2004) auditory training program in which greater improvement was achieved in a specific targeted skill (e.g. frequency discrimination) while other skills were much less responsive (e.g. time order judgement) to training. Using *f*MRI, Guenther, Nieto-Castanon, Ghosh and Tourville (2004) were able to show that auditory discrimination training in a small number of adults (n = 9) aged 18 to 55 years, led to a significantly increased amount of activation in the areas of the brain needed for accurate sound discrimination compared to pre-training levels of activation. The areas of note were Heschl’s gyrus and the planum temporale, thought to be important for pitch and phoneme perception. Veuillet, Magnan, Ecalle, Thai-Van and Collet (2007) were able to increase sensitivity to the onset of voicing within speech in dyslexic readers (age range: 8 years 4 months to 13 years 11 months) through audiovisual training. These studies support the notion of ongoing plasticity of the brain allowing improvement in different aspects of auditory processing.

Short-term auditory memory skills have also consistently been found to improve with age. Metsala (1999) achieved a significant correlation between short-term memory for digits and age in 3 to 5 year olds. Gathercole (1995) also found a significant increase in digit span between performance of 70 children at 4 years of age and re-tested at 5 years of age. Gathercole, Pickering, Ambridge and Wearing (2004) found that the three elements of working memory (episodic buffer, visuo-spatial sketchpad, phonological loop) were intact from 6 years of age, but operational capacity continued to increase into adolescence. Baddeley and Hitch (1994) propose that this reflects the increasing rate at which words can be encoded and rehearsed within the phonological loop . However, Roodenrys and Hulme (1991) proposed that the ability to recall real words more rapidly than nonwords reflects the importance of an existing phonological representation of the word in long term memory to aid short term recall. Alternatively, the quality of input may also affect the rate of encoding prior to rehearsal within working memory.

The developing child must learn to locate the source of sound, selectively attend to speech, discriminate sounds and acquire phonological and semantic representations of words (Gaskell, 2007). The phonological representations are based upon the incoming acoustic information in relation to frequency, intensity, timing and acoustic contours. A certain degree of deviation must be allowed for each phonological representation (Boothroyd, 1997; Gaskell, 2007). According to Kent (1997) these skills are not hard-wired at birth but are learned in an interactive environment. Rapidly changing stimuli are processed in the left auditory cortex whereas spectral information shows lateralization to the right auditory cortex (Warrier, Wong, Penhune et al., 2009), strongly indicating the need for interhemispheric communication for effective sound interpretation.

2.4.3 Relationship: Attention and Auditory Processing

There is much overlap in the behaviours of individuals with attention deficits and those with APD, in terms of difficulty following directions, needing repetition, difficulty with background noise and academic underperformance

(Tillery, Katz & Keller, 2000). A dual diagnosis of attention deficit disorder (ADD)/attention deficit hyperactivity disorder (ADHD) plus APD is not uncommon. A clinical database review of 183 children diagnosed with APD at one clinic found that of 70 children specifically evaluated for ADHD by independent paediatricians, 61 had been diagnosed with ADHD, representing 33% of the *total* sample (of 183 children) with confirmed concomitant APD and ADHD (Sanchez, 2004). In their paper calling for modality specificity in AP testing, Cacace and McFarland (2005) expressed a concern about the effect of attention deficits on performance during auditory processing assessment, especially in view of the reported co-morbidity of ADD/ADHD and APD.

Breier, Fletcher, Foorman, Klaas, and Gray (2003) assessed the auditory processing abilities of children with reading disabilities both with (n = 36) and without attention deficit (n = 40) and children with attention deficit without reading disability (n = 33). They found that the presence of attention deficit was associated with reduced performance on a range of auditory processing tasks. In a larger study, Weiler, Bernstein, Bellinger, and Waber (2002) investigated 224 children, aged 7 years 6 months to 11 years 11 months. The groups investigated were 24 children with attention deficit hyperactivity disorder (ADHD), 42 children with a reading disability (RD) and 9 children with both ADHD and RD. Performance on an auditory processing and visual processing task was compared between groups and to 149 controls. They found that students with diagnosed attention deficit hyperactivity disorder (ADHD) performed significantly poorer on the visual processing task (serial search), but not the auditory processing task (frequency discrimination) compared to students without ADHD. The auditory processing task required the participants to determine whether two tones heard were the same or different. Three durations (40, 75 or 250ms) and interstimulus intervals (10, 50 and 100 ms) were evaluated. The 51 children with RD performed significantly poorer on the auditory processing task but not the visual search task. This lends weight to the implication that there is a relationship between auditory processing deficits and reading disability.

Katz and Tillery (2005) found that children (n = 32) diagnosed with ADHD achieved the same performance on AP testing whether they were medicated or not, but performed better on a measure of attention when medicated. These results suggest a co-morbid condition rather than an inaccurate result on auditory processing assessment. Using case examples, Katz and Tillery (2005) argued that the responses of children with ADHD concomitant with APD can be readily distinguished by a competent audiologist from children with ADHD, but without APD.

2.4.4 Relationship: Phonological Working Memory and Auditory Processing

Stable phonological representations are necessary for efficient speech perception. When the acoustic features of the input (vowel harmonics, frequency, formants, timing aspects of onset/offset, duration, sequence , amplitude) are degraded this will affect the accuracy of those phonological representations (Eggermont, 2001).Written words and letters also access the phonological representation via visual word recognition. A phonological representation of a word can be constructed in PWM during grapheme-phoneme conversion of letters. When information in the phonological store is degraded and phonological representations are poor, information in PWM will decay and be lost.

Primacy and recency effects were first discussed by Mary Whiton Calkins in the early 1900s. When information fades rapidly from the phonological loop, only the most recent information is recalled. This ‘fade’ effect is usually exacerbated by background noise. It has been postulated that the recency effect occurs as a result of lack of tolerance for background noise (Katz et al., 1992) or lack of appropriate allocation of attention to the task (Medwetsky, 2002b). In contrast, loss of recent information, resulting in a primacy effect is thought to be the result of slower rates of processing also associated with individuals with APD (Medwetsky, 2002a). While a degree of primacy and recency effect is normal, both effects reduce PWM performance.

James, Van Steenbrugge and Chiveralls (1994) investigated PWM and AP abilities of children (age range: 8;6 to10;8) diagnosed with a language disorder and APD (APD group). All children were male and all had reading difficulty. Compared to controls matched for age and non-verbal IQ score (CA group) and another group matched for language age (LA group), the APD group had significantly poorer PWM ability, as demonstrated by three-way ANOVA analysis by group for nonword recall and real word serial recall. Performance in all groups was significantly affected by word length and phonological similarity of items. The phonological similarity effect was not significantly greater for the APD group but the APD group had poorer phoneme discrimination abilities. The researchers concluded that children with AP deficits experience PWM and phonological processing difficulty.

In verbal repetition tasks, auditory information needs to be phonologically encoded, whereas during reading, phonological decoding is necessary. Phonological decoding of printed linguistic units involves conversion of letters to sounds and blending or synthesis of those sounds to form a phonological representation of the word, thus making demands on PWM, before allocation of linguistic resources. Less-skilled readers are known to have difficulty with PWM for phonetically encoded material (Brady et al., 1983). In summary, the evidence to date indicates that PWM is a vital component in the efficient acquisition of the phonological and semantic representations of new vocabulary as well as the efficient decoding and subsequent semantic access of written words during reading. The evidence supports a relationship between AP deficits and poorer PWM ability.

2.4.5 Relationship: Intelligence and Auditory Processing

The relationship between intelligence and auditory processing was investigated by Deary (1995). An auditory inspection task (AIT) plus a verbal task (vocabulary) and a non-verbal task (Raven’s Coloured Progressive Matrices) were administered to 104 children at age 11 years and again at 13 years. The AIT is described as a temporal order pitch discrimination test. The task required the participants to listen to two tones of different pitch and varying duration and state the order of the tones e.g. high-low. The duration of the tones initially varied from 200ms to 6ms, however as no participants could perform accurately below 20ms, the briefer stimuli of 10ms and 6ms were omitted from the second trial, leaving a 15ms tone as the briefest tone tested. The task reflects speed of auditory processing. Three research questions were tested: does AIT performance predict later IQ scores, does IQ predict later AIT scores or is the relationship reciprocal? The findings supported the first hypothesis that AIT performance predicted later IQ performance and in particular verbal performance on the vocabulary task.

This seems to be consistent with a clinical database review by Sanchez (2004) in which the participants with APD (APD) had significantly lower overall IQ scores, lower verbal IQ scores and lower non-verbal IQ scores compared to the non-APD group. However, the mean IQ score for all participants with APD fell within the average range on the verbal scale, non-verbal scale and full scale, reported from a range of IQ instruments. The difference was greatest for verbal performance and least for non-verbal performance, suggesting that the results may be related to language skills. This suggests that the lower full-scale IQ score achieved by individuals with APD is the consequence of a lower verbal IQ score and may reflect difficulties with linguistic performance rather that IQ.

2.4.6 Co-morbidity: Auditory Processing and Reading Difficulties

A high co-morbidity rate of auditory processing deficits and learning difficulties has been consistently found since it was first reported by Samuel Orton (1937) in his seminal work which proposed that dyslexia (originally called congenital word blindness and later strephosymbolia) may have a neurological origin (Chermak & Musiek, 1997). This has led to the belief that both visual processing and auditory processing deficits are likely to be at least contributing factors to learning difficulties and at most, causally related (Sloan, 1980).

There is much support for the co-morbidity of APD and learning difficulties. Smoski et al. (1992a) found that of 64 students (age range: 7;1 to11;8, mean age: 9;3) diagnosed with APD, 55% of the students were participating in a special education program at the time. A diagnosis of APD was made when the student scored below two deviations or greater on at least one of the four tests in the test battery namely, the Selective Auditory Attention test, Pitch Pattern Test, Dichotic Digits and Competing Sentence test. In a study of 81 third-grade students by Domitz and Schow (2000), 25% of the students had been diagnosed with a language impairment, learning disability, attention deficit disorder or a combination of these. Of these diagnosed students about one third also scored 2 standard deviations below the mean on at least one auditory processing assessment within a battery of 4 tests covering auditory attention, pitch patterns and dichotic listening. Together, the studies above indicate a high prevalence of APD in the population receiving learning assistance.

There is a paucity of comparable literature for this study. As previously stated the bulk of the research has focussed on investigating the presence or absence of auditory processing deficits in individuals with reading difficulties, but not the reading abilities of students with known auditory processing deficits. Consequently, in the following studies it is necessary to pay particular attention to the reader type and the specific auditory processing skills under investigation.

Johnson, Nicol and Kraus (2005) report an increasing evidence base for the existence of abnormal brainstem responses by students with diagnosed learning disabilities. For instance, research by Banai, Hornickel, Skoe, Nicol, Zecker and Kraus (2009) has for perhaps the first time shown definitive correlations between neural phonological representations and reading in an unselected group of children aged 7 to 15 years (n = 46 to 55, according to reliable responses) with normal peripheral hearing and average intellectual abilities. Using auditory brainstem responses to the spoken syllable /da/ and comparing this to phonological awareness ability, reading ability on single word reading tests and nonword (word attack) reading tests (Woodcock-Johnson-3), moderate correlations were found firstly, for a number of measures of timing response latency for the syllable /da/ with phonological awareness, word attack and word reading. Weaker correlations were also found for harmonic encoding of the middle harmonic range of the syllable /da/ with phonological awareness and word attack. The middle harmonic range covers the frequency range of 410 to 755 hertz. Perception of the fundamental frequency was not correlated with phonological awareness or reading ability. It is proposed that the isolated nature of the syllable in this experiment, as opposed to environmental or connected speech, may mask deficits in rapid perception of changing pitch in natural speaking situations. They proposed that over time abnormal timing and harmonic perception could lead to 'abnormal shaping' of processing sounds. As a consequence phonological representations would be more unreliable making phonetic encoding more difficult. The researchers concluded that the findings provide good evidence that subcortical auditory function may be linked to the phonological processing deficits found in many poor readers. Even though the correlations are low to moderate these results provide the first hard evidence of AP abnormalities influencing the quality of phonological representations of speech sounds (Banai et al., 2009).

In contrast, the Benton–IU project (Watson et al., 2003) found no relationship between performance on auditory processing assessments and reading ability in their longitudinal study (n = 470) with a variety of measures taken in first grade and fourth grade. The auditory processing assessments included subtests of the SCAN-C: A Screening Test for Auditory Processing Disorders (Keith, 1986) and a measure of auditory memory that includes manipulation of the rate of presentation of the stimuli to determine whether the number of stimuli, rate of presentation of stimuli or both affected the attained score. Results were compared to teacher ratings of reading ability. While the majority of those students who had difficulty on the auditory processing assessments had greatest difficulty with hearing against background noise, there was no significant relationship with the reported reading achievement grades. Major limitations of this study include lack of formal assessment of reading in the form of nonword reading, word identification or text reading. The SCAN-C has also been widely criticised for poor reliability as discussed in the Method section of this paper. In addition, no measures of dichotic listening or PWM were performed.

Very few studies have investigated the impact of severity of AP deficits upon reading development. Share, Jorm, MacLean and Matthews (2002) found that the disabled readers with lower scores on TOJ tasks scored more poorly on phonological awareness, receptive vocabulary and reading tasks, though the difference compared to the higher scorers did not reach significance. Marshall, Snowling and Bailey (2001) found no significant relationship between severity of rapid processing deficits and degree of reading difficulty in dyslexic readers aged 8 years 8 months to 13 years 10 months. In the study reported above, Banai et al. (2009) established that abnormal brainstem responses were weakly correlated with the severity of listening comprehension and reading difficulties in the study group.

2.4.6.1 The rapid processing argument

Every speech sound has a central fundamental frequency around which other frequencies are produced in a specified pattern and within a certain range. The frequency and intensity pattern produced over very short duration (about 20 milliseconds) identifies the individual sound (Cestnick & Jerger, 2000). Some sounds are very similar in their formant patterns and can only be identified by the spectral changes that occur during the onset of the sound or the transition between that sound and the next sound. The speed of processing relies upon at least five factors, these being:

1) allocation of attention;
2) intensity of the stimulus: a stimulus above the hearing threshold will more easily activate stored information than a stimulus near the hearing threshold;
3) activation thresholds of stored representations from long-term memory: higher frequency items are more readily activated;
4) neuronal organization and connectivity: linked to the above in that higher frequency words or concepts have more established pathways to activate information;
5) phonological, semantic and syntactical representations and organisation, including prior knowledge of the word or topic
(adapted from Medwetsky, 2006).

Bellis (1996) stated that the first 100-250 milliseconds of a new auditory stimulus are the most critical for recognition of the stimulus. In this time, long enough for only two or three syllables, the listener determines the source of the sound and whether it is speech or not. Within connected speech, formant transitions from a consonant to vowel occur across a very brief 10 to 50 millisecond period (Cestnick and Jerger, 2000). Consequently, accurate speech perception necessitates rapid processing of auditory information. Boothroyd (1997) reports that detection of changes in sound patterns do not fully mature until 15 to 20 years of age. Any conflict, such as poor discrimination, extends processing time (Kane & Engle, 2000). This is true in all input modalities and is similar to the experience of requiring increased processing time when experiencing visual conflict between the letters ‘R’ and “B’ while reading further down the letter chart during an eye examination.

Willeford (1985) observed that while administering compressed (accelerated) speech subtests in the auditory processing battery this was sometimes the *only* subtest that some children were able to do well, while for others it was the *only* subtest that they were unable to do well. Compressed speech tests deliver the speech signal at an accelerated rate. The listener must be able to rapidly process the phonemes and phonemic units presented in order to process the words spoken. To do this, the listener needs to be able to receive a clear signal and analyse the signal rapidly in sequence while maintaining attention to the task. Willeford concluded that compressed speech taps a unique function of the auditory system.

As early as 1965, Lowe and Campbell found that children with language impairments needed a longer interstimulus intervals to determine the order of two tones (Lowe & Campbell, 1965). Tallal’s seminal work (1980) attempted to account for this as an auditory deficit of rapid perception. The methodology for her study will be explained as it has been utilized in many successive studies. Tallal’s participants were 20 students with SRD (mean age: 9;7) and 12 normal readers as controls (mean age: 8;5). The SRD students had a composite reading score that was at least one year below their chronological age. Tallal used the

Repetition Test in which two tones are presented in a series of subtests. One tone has a fundamental frequency of 100Hz (stimulus1) and the other a fundamental frequency of 305Hz (stimulus 2). Each tone was presented for a 75msec duration. Participants must firstly perform the Association Test whereby stimulus 1 must be associated with the bottom panel and stimulus 2 with the top panel on the response box until a criterion of 20 out of 24 correct is achieved. All participants reached criterion on the Association Test.

In the second Sequencing Test the two stimuli are then presented in succession and the participant must press the corresponding panels in order to indicate the *order* in which the tones were heard. This represents a task of temporal order judgment (TOJ) or auditory temporal order judgment (ATOJ). The inter-stimulus interval (ISI) between the presentation of the two tones was 428 milliseconds.

The third task is the Rapid Perception Test where the task is the same as the Sequencing Test but the ISI between the presentation of the two tones is reduced. The ISI is initially 428 msec but is then decreased to 305, 150, 60, 30, 15 and 8 msec. There was no significant difference between the two groups on their performance on the Sequencing Test with an ISI of 428 milliseconds. However, there was a significant difference between the reading impaired group performance and control group performance on the Rapid Perception Test as the inter-stimulus interval was reduced below 305 ms with the reading impaired group making significantly more errors as the ISI was reduced down to 8ms.

The final task was a Discrimination task in which participants were asked to judge whether two tones were ‘same’ or ‘different’. Tones were initially presented with a 428ms ISI. Once criterion was reached, the ISI was varied between intervals of 8 and 305ms as in the Rapid Perception Test. Again, there was no significant difference in the performance of the two groups when the ISI was 428ms, but significantly more errors were made by the reading-impaired group as the ISI decreased. Tallal concluded that the students with SRD have impaired ability to process rapidly presented acoustic stimuli (such as stop consonants), rather than poor temporal order judgment. A slowed rate of processing would result in the beginning of spoken utterances being processed but the remainder may be lost, observable by the primacy effect in short-term auditory memory tasks and frequently observed in individuals with APD. Tallal also strongly positively correlated performance on the Rapid Perception Test with the ability to read nonwords using Spearman correlations ($r = 0.81$, $p<0.001$).

Cestnick and Jerger (2000) replicated the findings for the Rapid Perception Test and also found significant correlations with both reading of nonwords and real words. Tallal speculated that the difficulty with processing rapidly presented stimuli was having an impact on the ability to discriminate between acoustically similar phonemes, particularly the rapid spectral changes immediately before the vowel. These spectral changes immediately prior to the vowel are referred to as onset transitions and occur over a 10-50ms duration (Cestnick & Jerger, 2000). These results were supported by (Reed, 1989) who found that participants with SRD had greater difficulty discriminating /ba/ vs. /da/, but no difficulty with a vowel discrimination task, suggesting difficulty processing rapid transitions. Tallal concluded that the impairment in processing rapidly presented stimuli, and *not* temporal order judgment per se, was influencing the ability to develop grapheme-to-phoneme conversion skills and the phonic skills necessary to decode unfamiliar words. This has been one of the great misconceptions in successive literature on the topic. Tallal (1980) states in her paper that:

> ….there was no significant difference on the Sequencing task (which does require perception of temporal order) and the Discrimination task (which does not require perception of temporal order). In addition, there was no significant difference between the reading impaired and normal children’s ability to sequence two successively presented stimuli as long as the stimulus sequence was presented relatively slowly. It was only when stimuli were presented more rapidly (by decreasing the interval between the offset of the first tone and the onset of the second tone) that reading-impaired children’s performance became significantly inferior to that of normal children. The finding that reading-impaired children performed equally poorly regardless of whether perception of temporal order was or was not required, suggests that the *rate* of presentation of perceptual stimuli may significantly influence performance on higher level perceptual tasks by interfering with the discrimination of the stimulus items to be processed. (p.193-194)

A number of successive studies unsuccessfully attempted to replicate Tallal’s work and in particular were unable to replicate the high correlations achieved between rapid processing difficulties and reading of nonwords (Heath et al., 1999; Nittrouer, 1999; Marshall et al., 2001). For instance, in a longitudinal study, it was found that while children entering school who were later diagnosed as SRD, did have difficulty on TOJ of non-speech tones on Tallal’s Repetition

Test, they had greater difficulty on longer ISIs than shorter ISIs (Share et al., 2002), the reverse of Tallal’s findings. Interestingly for the SRD group this may have implications for the processing of vowels instead of the briefer acoustic contrasts delivered by stop consonants. Of the school entry children (n = 543), 25 had been later diagnosed as SRD and 14 students as ‘generally backward readers’ by the time of the second sampling (n = 453) three years later at the end of Year 2. However, the ‘generally backward’ readers *did* have greater difficulty with the shorter ISIs, supporting the premise of this study that a subset of less-skilled readers (LSR) has AP deficits. Difficulties with the Repetition Test at school entry did correlate with poorer phonological awareness abilities at the same age, but did not predict later phonological awareness or reading ability. Temporal processing deficits *did* predict later receptive vocabulary as well as reading comprehension weakness. In another study, Cohen-Mimran and Sapir (2007) investigated a small group of children with SRD (n = 12) and without SRD (n = 12) (age range: 10;7 to 13;1) and found that children with SRD had significant difficulty discriminating between pure tones with short (50ms), but not long (500ms) inter-stimulus intervals, supporting Tallal’s findings and conflicting with Share et al.’s (2002) results. Once again, the composition of the reading impaired group may be the critical factor in the outcome. Overall, despite conflicting findings it cannot be said that Tallal’s conclusions have been refuted. Dawes and Bishop (2009) offer the following:

> An explanation offered for failure to replicate (Tallal’s) findings is that there is an inherent heterogeneity within the SLI/dyslexia

> population, and that a subgroup of children has perceptual deficits that underlie their language or reading difficulties. (p.455)

2.4.6.2 The auditory temporal order judgement argument

A number of studies have concentrated specifically on the temporal aspects of speech processing, yielding some interesting results. The tasks are commonly called auditory temporal order judgement (ATOJ), auditory temporal processing or temporal ordering. ATOJ requires that firstly, two stimuli are perceived as separate, and secondly, the *order* of the stimuli is correctly recalled. Hirsh (1959) determined that the normal listener needs a 2 msec inter-stimulus interval to separate two sounds, but a 17 msec interval to be able to state the order of the sounds with 75% accuracy.

Tallal is often falsely reported to support a view that ATOJ deficits underlie the difficulty with phonological perception, possibly because of her use of the term ‘auditory temporal perception’ in the title of her controversial paper. Both rapid processing and ATOJ are (correctly) referred to as auditory temporal processing, but as Studdert-Kennedy and Mody (1995) point out, they are not the same thing. They state that: “perception is temporal if the defining property of the perceived event is temporal; it does not become temporal by virtue of being effected rapidly” (p.508).

ATOJ deficits have also been questioned as to whether they simply reflect attentional difficulties or intellectual difficulties. Farmer and Klein (1995) reviewed the literature on this topic and discarded the notion that temporal processing deficits reflect attentional disorder. For instance, children with temporal processing difficulties were able to demonstrate good attentional abilities on a range of cognitive tasks.

Tallal (1980) noted that the performance of only 9/20 (45%) of the SRD participants was impaired on the rapid processing tasks and Cohen-Mimran (2007) had a finding of 9/12 (75%) participants performing more poorly than controls. Tallal postulated that this group might represent readers with SRD plus concomitant language difficulties. This was supported in a follow-up study by Tallal and Stark (1982) who concluded that ATOJ deficits were correlated with oral language but not to reading difficulty. Their comparison groups consisted of reading impaired subjects with normal language vs. normal readers with normal language. Neither group had difficulty with ATOJ. They did not investigate readers with SRD or LSR with language deficits, but refer to previous literature in which ATOJ deficits have been found in reading-impaired subjects who have not been controlled for language.

Heath *et al.* (1999) investigated this possibility by separating SRD readers into two groups and comparing the results to normal readers in the 7 –10 year age range. The SRD group had a reading accuracy age at least 18 months below chronological age on the Neale Analysis of Reading Ability – Revised with normal oral language skills as evaluated on the Clinical Evaluation of Language Fundamentals -Revised (CELF-R). The second group had a specific reading disability plus concomitant oral language delay when their language scores fell below 85 on the CELF-R and were labelled the LDRD group. Tallal's Repetition Test was repeated as well as the nonword reading (Word Attack) subtest of the Woodcock Reading Mastery Test - Revised (WRMT-R) and the Martin Nonword Reading Test. (Heath et al., 1999) applies the encompassing term 'auditory temporal processing' to "denote the ability to process auditory information that is either brief in character or presented rapidly" (p.637), justifying this as being consistent with current literature. (Heath et al., 1999) was unable to replicate Tallal's finding that SRD readers had greater difficulty than normal readers on the Rapid Perception Test at shorter ISIs casting doubt over Tallal's theory that phonological deficits are caused by deficits in rapid processing. All three groups had greater difficulty with shorter ISIs, with normal readers performing slightly better, but the effect for groups was not significant. Given that the participants in Heath *et al.*'s study were both younger and more severely reading-impaired than those in Tallal's study, these findings seem inexplicable. Heath *et al.* offer the explanation that their participants required more trials to reach criterion and therefore, may have been more practiced at the task.

However, on a further test of ATOJ using the PEST procedure (Heath et al., 1999) did find ATOJ deficits, with the LDRD group performing significantly poorer than controls. In the PEST probability procedure a score was calculated based on the inter-stimulus interval (ISI) at which the participant could identify a gap between two stimuli (working step-wise down from 200ms) *plus* the order of those stimuli, with 75% accuracy (Taylor & Creelman, 1967). When the SRD group was divided into High-Language-Ability and Low-Language-Ability subgroups with no overlap on language scores there was a significant difference on ATOJ results with the Low-Language-Ability subgroup results closely resembling the overall LDRD results. Therefore, ATOJ may be an indicator of the severity of language delay. The above study highlights the importance of separating readers with and without language difficulty both in research and intervention practices.

On the WRMT-R Word Attack (nonword reading) subtest, Heath et al. (1999) found that both the SRD group and LDRD group performed significantly poorer than the normal readers. On a nonword reading test the performance of LDRD group was poorer than the SRD participants who in turn were poorer than the normal readers resulting in a significant difference across all groups. Correlations between the rapid perception test and the reading of nonwords for the whole group were non-significant. So while the LDRD group was more impaired in their ability to read nonwords, the SRD was also impaired. Heath et al. (1999) concluded that ATOJ deficits cannot account solely for the reading deficits in students with SRD and normal language.

The studies by Heath et al. (1999) and Tallal and Stark (1982) are the only studies, to the author's knowledge, that have sought to separate poor readers with and without concomitant oral language delay. However, it must be acknowledged that only 7 of the 14 participants in the LDRD group (reading disability plus oral language delay) had temporal order processing deficits in the Heath et al. study indicating that ATOJ deficits cannot solely account for the oral language deficits in this group either. The SRD and LDRD participants with normal ATOJ results still had difficulty with the nonword reading task, precluding ATOJ as being causally linked to the phonological skills required for this task. The findings of Heath et al. (1999) provide compelling evidence in relation to the co-morbidity of auditory processing deficits in language impaired children with SRD in which only those children with concomitant language impairment exhibited auditory processing deficits. This lends weight to the proposition that auditory processing deficits are one contributing factor to language deficits that may have a detrimental impact on reading ability.

2.4.6.3 The phonetic encoding argument

Phonetic encoding refers to the ability to encode meaningful perceptual units of speech heard to their corresponding phonetic label. Gathercole and Baddeley (1993) explain it as follows:

> …one dominant perspective is that children's metalinguistic abilities reflect the adequacy of their phonological coding in the language system. According to this type of account, poor readers have weak and poorly specified phonetic codes that impair their abilities to make explicit judgements about, for example, phonetic structure. (p.167-168)

For instance, Manis et al. (1997) found that participants with phonological dyslexia (n = 25; year level 4 to 10) had greater difficulty with the discrimination of the words 'bath' vs. 'path' than the control group and dyslexic participants without phonological difficulty and suggest that this was possibly due to phonetic encoding or 'labelling' difficulty. Brady, Shankweiler, and Mann (1983) investigated whether the short-term auditory memory deficits observed in poor readers can be explained by difficulties with phonetic encoding. In their study participants were all selected from third grade in a public school on Rhode Island. They were allocated to the 'poor' reader or 'good' reader groups according to the lowest scorers (mean age: 8;6) and highest scorers (mean age: 8;5) on the Woodcock Reading Mastery Tests (WRMT). There was a significant difference in the reading scores between groups. They hypothesised that poor readers would perform normally on non-speech tasks but poorly on tasks in which the auditory stimulus can be phonetically encoded i.e. speech. The speech discrimination performance of the less-skilled readers was significantly impaired in the presence of an amplitude-matched noise signal derived from the digitized waveform of the speech sample, compared to good readers as previously reported in this review. The presence of background noise is assumed to degrade the quality of the input signal. This effect was not borne out. In fact, the poor readers performed slightly better than the good readers in the perception of environmental sounds in the presence of noise, though the difference did not reach significance. It was concluded that poor readers perform poorly on auditory short-term memory tasks due to speech-specific perceptual deficits when the quality of the speech signal has been degraded. However, it must be pointed out that the AP status of individuals in the LSR group is not known and therefore it cannot be stated with confidence that individuals with APD do not also have difficulty with non-speech input (Wilson et al., 2004).

Brady *et al.* (1983) challenged Tallal's claims regarding rapid processing and its effect upon phoneme perception in favour of the phonetic encoding theory. Using the same study group outlined above they devised word lists of five monosyllabic words, composed of rhyming and non-rhyming word strings which the participants were required to repeat. Good readers recalled non-rhyming word strings better than rhyming word strings as expected, due to the phonological similarity effect. Poor readers made more errors on both item types. There was less difference between performance on the rhyming and non-rhyming conditions in the poor readers, as per other studies previously mentioned in this review. They concluded that the lack of the phonological similarity effect was evidence for a phonetic encoding deficit in poor readers. This finding conflicts with James et al.

(1994), reviewed previously, who found that poor readers with APD were affected by the phonological similarity effect to the same extent as controls. Poor readers made significantly more sound transposition errors on the non-rhyming word lists than on the rhyming word lists. The poor readers made other error types including provision of words from previous strings, or provision of phonetically unrelated words, suggesting the use of non-phonetic strategies to assist recall. The poor readers also made more errors in the *order* of word recall, supporting the view that poor readers have difficulty preserving the sequence of phonological input in PWM.

Mody et al. (1997) investigated ATOJ of paired syllables in second-grade readers (age range: 7;0 to 9;3) with a reading age at least 5 months below chronological age. They found that ATOJ was not impaired when the syllables were phonologically distinct e.g. /ba/-/sa/, but less-skilled readers had difficulty with between the syllable pair /ba/ - /da/. It was concluded that this was due to phonetic similarity. This was further tested by a non-speech task in which the same participants were asked to judge non-speech sounds containing sine waves of the same durations and frequencies as /ba/ and /da/, but that do not resemble these speech sounds. The participants had no difficulty with this task, even at shorter ISIs. They conclude that the difficulty discriminating /ba/ and /da/ arises because of a perceptual confusion rather than an ATOJ deficit. In their critical review of the evidence Studdert-Kennedy and Mody (1995) concluded that the phonological deficits in less-skilled readers are due to a speech-specific difficulty in discriminating phonemes, especially when they are phonetically similar and do not reflect deficits of ATOJ or rapid perception of auditory stimuli. They purport that temporal order judgement tasks are simply stressing cognitive discriminatory capabilities, especially when two stimuli are presented rapidly. Studdert-Kennedy and Mody (1995) do not proffer a source of the perceptual confusion stating that: “the full nature, origin and extent of the perceptual deficit remain to be determined.” (p.513)

Other studies report difficulties with speech perception amongst subgroups of participants with SRD, particularly for consonant discrimination (Adlard & Hazan, 1998) while no difficulties with the discrimination of non-speech stimuli were found for the same subgroups. However, across two papers, Farmer and Klein deny the existence of speech-specific areas believing that some non-speech sounds are processed in the same location as speech (Farmer & Klein, 1995; Klein & Farmer, 1995). They also do not accept that phonetic encoding is required for ATOJ tasks. The real question here seems to be to what extent phonetic encoding is a metalinguistic labelling/naming skill or an issue of stable and well specified phonological representations. Studdert-Kennedy and Mody (1995) concede that a more comprehensive understanding of the cause of phonological deficits in LSR remains elusive. As a conciliatory position, Farmer and Klein (1995) suggest that the presence of temporal order deficits *and* rapid processing deficits may underlie phonetic encoding deficits and that the two positions need not necessarily be in conflict.

2.4.6.4 Frequency discrimination

As early as 1975, poorer interpretation of intonation, difficulty with sentence repetition and poorer language abilities were observed in emergent poor readers, compared to controls (Vogel, 1975). These findings suggest a link between prosody perception and both language and PWM in some poor readers. Using positron emission tomography (PET) measurements, pitch and melody perception has been found to increase cerebral blood flow to the right superior temporal cortex and right frontal lobe (Zattore, Evans & Meyer, 1994). The right hemisphere is therefore thought to play a major role in the interpretation of the speaker's intent and emotional state. The information from the right hemisphere needs to be integrated with the linguistic information being processed in the left hemisphere in order for accurate comprehension of the message to occur.

When (Heath et al., 1999) examined their data they were puzzled by the variability in performance on the ATOJ task by the control subjects. The range of ISI on this task evaluating the ability to correctly detect the order of the two tones was as wide as 1ms to 190ms. They postulated that this variability could possibly be accounted for by difficulty with frequency discrimination that while intact at criterion with an ISI of 500ms, broke down under shorter ISIs. This was supported in the work of Cestnick and Jerger (2000) and Fischer and Hartnegg (2004).

Ahissar et al. (2000) found that adults with a childhood history of reading difficulty (CHRD) had significant difficulty compared to participants with no history of reading difficulty on a frequency discrimination task in which two tone pairs were presented and the adults labelled the pairs as consisting of 'same' or 'different' tones. The tone pairs were two 70dB SL tones of 250ms duration in the range of 60-1,400Hz, separated by an 800ms gap. On average the CHRD group required a 150Hz difference to be able to discriminate between two tones at around 1000Hz compared to the 40Hz required by the good readers. Reading abilities were evaluated on the Woodcock Reading Mastery Tests (WRMT). Moderate correlations between frequency discrimination and nonword reading were also found. Stronger correlations were found for the ability to discriminate frequency in a backward masking condition with the ability to read real words (r = 0.67). Ahissar at el. (2000) concluded:

> …these findings are consistent with the hypothesis of general and fundamental deficits in auditory perception underlying poor reading…. impaired acoustic processing is directly related to reading impairment. (p. 6836-6837)

Sharma, Purdy, Newall et al. (2006) compared the auditory processing abilities of students (age range: 8 to 12 years) with a reading disorder to a control group. All students in the reading disorder group failed at least one test in the auditory processing battery composed of pitch patterns (Frequency Pattern test), dichotic listening (Dichotic Digits), temporal resolution (Random Gap Detection Test) and hearing against background noise (Speech-in-Noise test). They concluded the co-morbidity of reading disorders and APD was supported. A follow -up study of children suspected to have AP deficits (n = 68) showed that of the 49 children within the study who met the criteria for APD, about half of these children had concomitant language and reading difficulties. These were also the same children who had greatest difficulty with frequency discrimination (Sharma, Purdy & Kelly, 2009). This is in agreement with the findings of Weiler et al. (2002) who investigated 179 children, (age range: 7;6 to 11;11), and found that students with reading disability performed significantly poorer on the auditory processing task (frequency discrimination) than students without reading disability.

Talcott et al. (1999) and Witton et al. (1998) put forward a convincing argument that nearly 40% of the variability on phonological (phoneme transposition) and nonword reading tasks by normal readers can be predicted from performance on a frequency discrimination task. The phoneme transposition task requires the subject to delete and insert a phoneme e.g. “say ‘top’, but say ‘m’ instead of ‘t’”. The auditory task required discrimination of a modulation in frequency of 2Hz, presented within a 1kHz carrier tone. This was not upheld for a modulation of the frequency greater than 240Hz. Talcott et al. (1999) concluded that this demonstrated that it is low levels of frequency modulation that are essential for the development of strong phonological skills. The findings suggest that auditory processing ability may be able to predict reading ability in normal readers (Rosen, 2003). In conclusion Talcott et al. (1999) state:

> ….such a finding suggests that basic auditory skills can constrain phonological development and therefore also reading ability. It also implies that the phonological problems of language impaired populations may also result from impaired acoustic perception rather than deficits specific to linguistic processing. (p. 2047)

Results have not been consistent however. Bishop, Carlyon et al. (1999) found no relationship between performance on frequency modulation tasks and nonword repetition or nonword reading ability. The positions taken on the relevance of frequency discrimination also vary widely. Moore (2007) states that poor frequency discrimination ability is a strong indicator of dyslexia and certainly more reliable than ability on TOJ tasks. In contrast, Rosen (2003) states that once you know someone has phonological dyslexia, they will have difficulty with nonword reading and therefore their auditory processing abilities are irrelevant in relation to nonword reading. Cestnick and Jerger (2000) take the position that discrimination tasks also reflect memory and cognition. Poor results could reflect difficulty with categorisation, PWM and naming or retrieval. This would seem to fit with the known features of dyslexia. However, in the population with APD, auditory discrimination difficulty would be more likely to occur due to slower rate of input processing, TOJ deficits and/or frequency discrimination difficulties. If these APD individuals are also poor readers, any poor reader sample is likely to contain some readers with APD and therefore yield variable findings of impaired rapid processing, ATOJ deficits and frequency discrimination difficulties in a variable percentage of the sample. This would explain the confusing and at times, conflicting results.

In summary a number of studies have consistently showed impaired ability to detect changes in frequency (Witton et al., 1998; Talcott et al., 1999; Ahissar et al., 2000) in some poor readers. Further, the *relationship* between these discriminative abilities and both phonological awareness abilities and reading abilities is strong in both skilled and less-skilled readers (Witton et al., 1998; Talcott et al., 1999). Specifically, the ability to detect changes in frequency was strongly correlated with phoneme transposition tasks and nonword reading.

It seems that in combination, deficits in the ability to process auditory information rapidly and to discriminate changes in frequency would be sufficient to cause difficulty with phoneme discrimination. As previously proposed by Farmer and Klein (1995) the presence of rapid processing deficits, temporal order deficits or frequency discrimination difficulty may underlie difficulty with the seemingly cognitive task of phonetic encoding observable in auditory discrimination tasks. In the absence of a clear conclusion about the role of rapid auditory processing, the contribution of frequency discrimination seems worthy of further consideration as to the potential influence on phonological representations, the development of phonological awareness and the development of vocabulary.

2.4.6.5 Section Summary

The above studies show that individuals with language impairment, learning difficulties and reading disabilities tended to perform more poorly on auditory processing tasks. It can be seen that the findings to date have been inconclusive and at times, conflicting. To reiterate, evidence for auditory processing deficits have been found in individuals with reading disabilities in some studies (Sharma et al., 2006; Banai et al., 2009), yet not in other studies (Watson et al., 2003) or only in individuals with concomitant language difficulties in other studies (Heath et al., 1999). It would seem therefore, that auditory processing deficits are present in only a percentage of individuals with language impairment and/or reading disorders. The role of AP deficits in language and reading difficulties can be summarised as follows:

- TOJ difficulties (judging the order of two different frequencies) under rapid processing conditions in a percentage of participants with reading difficulty (Tallal, 1980; Cohen-Mimran, 2007; Adlard & Hazan, 1998)

- TOJ difficulties only in those participants with reading difficulty and concomitant language difficulty (Heath, Hogben and Clark, 1999)
- Some researchers conclude that auditory discrimination difficulty is the result of poor cognitive phonetic encoding (Brady et al., 1983; Manis et al., 1997; Mody et al., 1997)
- Farmer and Klein (1995) suggest rapid processing and TOJ difficulties possibly underlie phonetic encoding capabilities
- Abnormal brainstem responses (timing and harmonic encoding) to syllable /da/ correlated with phonological awareness and reading skills in a percentage of participants (Banai et al., 2009)
- Strong evidence put forward that nonword reading in normal readers can be predicted from frequency discrimination ability (Talcott et al., 1999; Witton et al., 1998)

It is likely that the inclusion of both LSR and dyslexic readers in ‘poor’ reader groups has resulted in some of the conflicting findings to date. Bishop and McArthur (2005) also make a very important point though that if auditory processing skills are delayed in the early years but are subject to maturation, possibly to adult levels, then there will be great variability in the deficits found across studies, depending on age at investigation.

2.5 Receptive Language

2.5.1 Listening Comprehension

Successful listening comprehension relies upon many processes including:

a. attention, as already reviewed;
b. speech perception, as already reviewed;
c. phonological input buffer or PWM, as already reviewed;
d. long-term memory; the phonological input lexicon (vocabulary store) reviewed in the forthcoming section 2.5.2, the semantic system (matching vocabulary to meaning) reviewed in the forthcoming section 2.5.3 and the syntactic system reviewed in section 2.7.1;
e. cognitive integration of information with knowledge about the world, mediated by the central executive as previously discussed

(Nation, 2005).

Each component above is therefore critically important but not sufficient for listening comprehension alone. Investigation using *f*MRI has shown that listening comprehension tasks activate areas in the superior and middle temporal regions closely located to the primary auditory cortex and access semantics from both left and right temporal regions (Michael, Keller, Carpenter & Just, 2001). Of course, this is not surprising give the known auditory pathways, with verbal information crossing the corpus callosum to access the linguistic regions in the left hemisphere. However, the patterns of activation are different for reading comprehension, as reviewed in section 2.7.3.

Processed auditory information can be viewed as the product of perception and cognition. The information is encoded for storage in long-term memory, consciously or unconsciously, ready for later retrieval. If the information is verbal, then the cognitive processing includes linguistic processing. The more times the same information is encoded, the stronger (perhaps clearer) the access pathway to that information. Impaired perception, linguistics or cognition can affect the quality of the encoded information.

Within the long-term memory (LTM) storage repository resides two forms of memory: procedural (implicit memory) and declarative memory (explicit memory) (Gazzaniga et al., 2002). Procedural memory comprises memory for skills (e.g. riding a bike) and classically conditioned responses (e.g. salivation). Declarative memory is divided into episodic memory of experiences and semantic memory of facts and knowledge. Linguistic knowledge is stored within semantic memory and encompasses phonological knowledge, semantic knowledge and syntactic knowledge (Butler, 1983). Information stored in long-term memory can be activated by short-term memory input for the purpose of listening and reading comprehension. Once activated and retrieved the information is sometimes considered to be in long-term working memory (LTWM) (Kintsch, Patel & Ericsson, 1999). Kintsch et al. used the flashlight analogy whereby STM shines small beams of light into LTM. The lighted areas become active, together with their links still in darkened areas of LTM. The lighted and linked areas form LTWM. The stronger the links, the more automatically they are retrieved. Attention processes then inhibit irrelevant information, leaving the gist of the meaning (Kintsch et al., 1999).

During the listening comprehension task, there is debate whether the complete unprocessed message is held in PWM prior to long-term memory involvement or whether the message is processed word-by-word or in cycles corresponding to propositions (Gathercole & Baddeley, 1993; Kintsch et al., 1999). Irrespective of which contention is correct, the phonological loop in PWM is involved and it is known that PWM capacity increases with processing speed (Gathercole & Baddeley, 1993). The amount of information held in PWM will depend on the available capacity and the complexity of the input (Kintsch et al., 1999). For instance, a complex sentence that relies on sequential order (e.g. passive structures such as “The boy was on the swing that was pushed by his sister”) will be more demanding of PWM capacity than interchangeable order (e.g. “The girl played on the slippery dip and the see-saw”). Linguistic and episodic information is then retrieved from long-term memory to access meaning in the episodic buffer. While a complete understanding of the long-term memory processes involved in comprehension remains elusive, there is little doubt that the efficiency of processing information in PWM will have an impact on listening comprehension.

2.5.2 Vocabulary Acquisition

In the PALPA model (shown in Figure 1), long-term memory has two components relating to spoken input: the phonological input lexicon and the semantic system (Kay et al., 1996).

The notion of a mental lexicon or ‘dictionary’ first appeared in the early 1960s (Coltheart et al., 2001). One of the functions of the phonological input lexicon is “to transfer phonologically analysed material out of the limited memory store and push it upward (sic) at the same time freeing the storage area to accept the next chunk of phonological material” (Shankweiler, 1989, p. 59).

In word repetition tasks a real word will activate the semantic system whereas a nonword will not. A nonword will be directed to the *phonological output buffer* (see PALPA model in Figure 1) for construction of a motor plan. Evidence for these two separate pathways have been provided by studies demonstrating prolonged repetition times for nonwords compared to real words (Baddeley & Hitch, 1994) and the loss of ability to repeat nonwords in some aphasic patients while retaining the ability to repeat real words (Kay et al., 1996). Keith (1984) also concluded that nonword consonant-vowel (CV) units are not processed semantically as there was no evidence of a right ear advantage in a dichotic listening task requiring repetition of the nonword syllables. It could be argued that the lack of right ear advantage occurs because of the light phonological/linguistic load of the syllables or alternatively, equal hemispheric processing of the syllables. The assumption in the PALPA model is that only real words are contained within the phonological input lexicon.

Vocabulary development is a remarkable human feat. There are more than 500,000 words (excluding technical and scientific terminology) in the English language making it the world’s richest language in terms of vocabulary (McCrum, Cran & MacNeil, 1992) though about 200,000 would be considered to be in common use (Bryson, 1990). It is estimated that by 4 years of age a normally developing child can understand between 2,500 to 3,000 words and by the age of 10 years this number increases to about 40,000 words (Metsala, 1999). The average rate of acquisition between 18 months and 18 years is 10 words per day or more than 3,000 words per year (Brackenbury & Pye, 2005). However, there are significant individual differences in vocabulary acquisition which have been attributed to wide-ranging causes including the amount and frequency of language exposure, history of otitis media (inner ear infection), hearing ability, visual ability, attention, cognitive ability and auditory processing abilities.

In contemplating this area, it is necessary to consider the process of acquiring a new word in the lexicon. The new word (e.g. 'bobcat') is heard and is phonologically analysed as a new sequence of sounds not previously encountered. For perception of meaningful sounds, the representation is coded at the auditory cortex (Eggermont, 2001). Cognition and attention is required to assemble the information to form the code, compare that information to existing representations and search for a phonological and semantic relationship. The meaning must be extracted from the context: Any new word needs to classified according to its semantic category i.e. whether it is a vehicle or an animal. The object itself needs to be visually analysed and differentiated from a known vehicle such as 'car' before adding it to the lexicon of vehicle names. Words that are more concrete (e.g. relate to a tangible object) that can be more easily visualised are more readily acquired, whereas linguistic concepts e.g. 'however' are more difficult (Vellutino et al., 1995). Frequency of exposure to a particular lexical item is also a significant factor in acquisition (Metsala, 1999). The new word then needs to be stored in the long-term lexicon according to the phonological, semantic and syntactic information that has been gleaned. To use the new word expressively, it must be accessed and retrieved from storage.

Carey and Bartlett (1978) identified two stages of word acquisition. In the first 'fast' mapping stage after one or very few encounters with the word, the child acquires a phonological code for the word that is stored in the phonological input lexicon. However, the representation of the word's meaning is likely to be incomplete. Over the 'extended' mapping phase, the word becomes fully understood in terms of its inclusions, exclusions and usage. This information is stored in the semantic system. The process of applying the phonological code to form a stable phonological map with appropriate semantic links may take many months. The assumption is that children who can 'fast map' a word will readily acquire new vocabulary items whereas children who have difficulty with the fast mapping of the phonological code will have the greatest difficulty acquiring new words.

Gathercole and Baddeley (1993) purported that the ability to temporarily store a new word (fast map) will affect the ability to store the word in long-term memory. Gathercole and Baddeley also suggest that nonword repetition tasks are a more sensitive measure of fast mapping ability than digit span or word repetition tests because there is no pre-existing phonological representation of the nonword in long-term memory. Consequently performance is not confounded by the individual's existing lexicon. It is argued that the phonological representations of the existing lexicon can influence performance on repetition of nonwords especially if the word is a pseudohomophone i.e. phonologically similar to a real word (Hulme & Roodenrys, 1995; Snowling & Stackhouse, 1996; Metsala, 1999).

Nonwords can be rated according to wordlikeness. For example, phonological short-term memory for the nonword 'trebulous' may be assisted by lexeme knowledge of the word 'fabulous' or 'tremulous' if they are in the existing lexicon. In support of this, the wordlikeness measure correlated significantly with repetition accuracy in both 4 and 5 year olds (Gathercole, 1995). Greater resemblance to a real word increased the likelihood that the word would be repeated accurately, due to the overlapping phonological representations in long-term memory. Therefore, PWM is needed to a greater extent for learning new words in the absence of any existing support from long-term memory. However, successful repetition of nonwords is also predictable from the length of the nonword, indicating the involvement of PWM. Gathercole et al. (1992) conclude that both linguistic knowledge and PWM play a significant role in nonword repetition performance. Consequently, the less that a nonword item resembles a real word, the greater that item will test PWM ability.

An important question is whether PWM assists vocabulary as Gathercole et al. (1992) predicted or whether vocabulary assists PWM. After 5 years of age vocabulary scores predict later nonword repetition ability more strongly than nonword repetition scores predict later vocabulary performance in normally developing children (Gathercole, Pickering, Ambridge et al., 2004). During the period of four to six years of age, correlations between nonword repetition and receptive vocabulary range between 0.52 to 0.56, but after the age of eight the correlation falls to a non-significant level at 0.28 (Gathercole et al., 1992). Gathercole et al. (1992) have also proposed that cognitive development may become more important for vocabulary development beyond 5 years of age, in extrapolating meaning of new words both in spoken language and reading. In accord with this, Snowling et al. (1986) suggested that impoverished reading experience may have limited the performance of dyslexic subjects aged 9 to 12 years on a nonword repetition task compared to average readers, due to reduced vocabulary. Metsala (1999) also agreed with the latter view, adding that vocabulary development assists phonological development which in turn aids the development of PWM. Brackenbury and Pye (2005) have also concluded that the relationship between PWM and vocabulary is reciprocal.

A strong phonological representation of a word allows rapid recognition of spoken words. In the emergent stages of language acquisition, phonological representations are assumed to be weak. Metsala (1999) suggests that phonological representations, that influence spoken word recognition and vocabulary development, continue to develop into the early school years. The factors which ensure strong phonological representations are not well understood. However, the presence of AP deficits could potentially inhibit both PWM and vocabulary learning.

Brackenbury and Pye (2005) reviewed the literature pertaining to vocabulary development in individuals with language impairment (LI). They identified three key areas that have been explored in depth. These are the abilities to:

a) perceive and isolate the phonological form from the ongoing stream of information;
b) hold the phonological form in short-term memory while a lexical search is activated;
c) extract the correct meaning of the new word to be paired with the phonological form

(Brackenbury & Pye, 2005, p. 6).

In relation to the first area above, Brackenbury and Pye assert that there is insufficient evidence to suggest that individuals with LI have difficulty with perception or isolation of the phonological form. In contrast, individuals with

APD have known difficulties in this area, especially in the presence of background noise (Hull, 1999; Jerger & Musiek, 2000; Wible et al., 2005; Veuillet et al., 2007). The temporary trace of a new word must be stored in the long-term lexical-semantic system if it is to be recognised or recalled. Gathercole and Baddeley (1993) propose that: “the more distinctive and durable the temporary trace is in the phonological loop, the more readily a stable long-term memory representation can be constructed” (p.71). It has been shown that the presence of background speech affects recall of a spoken word list and this is precisely the most prominent feature of APD (Gathercole & Baddeley, 1993, p. 12). Background speech interferes with the integrity of phonological storage. Background speech can even affect memory for pictured items because there is interference with phonological storage. Therefore, while perception and isolation of the phonological form may not be relevant in SLI, it is more relevant for the APD population.

In relation to the second area above, again it is known that individuals with both SLI and APD have significant difficulty with PWM tasks such as digit recall and sentence recall (Katz et al., 1992; James et al., 1994; Hull, 1999; Medwetsky, 2006), suggesting difficulty holding the phonological form while activating the lexical search. Gathercole et al. (1992) proposed that a purer but less efficient method of evaluating PWM may be the learning of novel vocabulary items, associated with meaning. The effect of PWM on language development is then being directly targeted. A number of studies have detected deficits in the ability of children with SLI to sufficiently hold and subsequently reproduce novel words presented rapidly. That is, children with LI may perceive the input perfectly well, but cannot recall it well. Gathercole and Baddeley (1993) propose that this is consistent with the hypothesis of impairment in the phonological loop in SLI. Brackenbury and Pye proposed that poor nonword repetition may be due to a trade-off of attention given to processing vs. storage in working memory, as per capacity theory. The central executive determines how much attention will be given to processing and how much attention to storage (Just & Carpenter, 1992). When language is impaired, the processing load may be greater, diminishing the attention allocated to storage.

Metsala (1999) found that the ability of 3 to 5 year olds to repeat nonwords was strongly associated with their vocabulary level, using nonwords (8 of each 1, 2, 3 and 4 syllables) that would tax PWM abilities. Metsala (1999) proposed that as vocabulary develops children must increasingly distinguish between words that are phonologically similar e.g. ‘cat’ and ‘cap’. This is referred to as the degree of ‘neighbourhood density’: the greater the similarity, the higher the neighbourhood density. Metsala (1993) proposed that the process of making these discriminations in turn develops phonological awareness. The emergent theory of phonemic awareness arises out of this ability to distinguish between words with high degrees of neighbourhood density.

It is debatable whether a single exposure to a nonword would lead to long-term storage and it is also debatable whether a nonword repetition task of a short word (<2 seconds) would require PWM involvement beyond the phonological loop, though longer words may. Munro and Lee (2004) tested phonological loop function vs. PWM by exposing children aged 4 to 6 years to 12 novel CVC words, presented as ‘jungle language’ across a six-week period. They found that children with language impairment (n = 17) were able to ‘fast map’ novel CVC words after a single presentation but were significantly poorer at recalling these novel CVC words presented auditorily as a list of 12 words than age-matched controls (n = 19). Where the typically developing controls could recall 6 of the 12 words on average, the language impaired group could recall 3 or fewer words. It would seem therefore that the phonological loop is intact for children with language impairment, but they exhibit poor PWM.

To test the relationship between phonological memory and vocabulary in primary-aged students, Aguiar and Brady (1991) taught novel vocabulary items and their definitions (semantic learning) to nine and ten-year old children and compared retention of the new items with reading accuracy, intelligence and working memory. In regression analysis, reading accuracy was found to make the greatest contribution to new word learning, whereas short-term phonological memory, as measured on digit span did not. However, the vocabulary task required recall of the correct phonological sequence of the novel items and not the definition. There was not a significant relationship between the learning of definitions and reading accuracy or memory skills in the Aguiar and Brady study, but IQ scores predicted semantic learning. While digit span tests short-term phonological memory it is not usually considered to be a working memory task. PWM was not evaluated, and therefore this may provide an explanation for the finding that vocabulary and semantic learning were not related to (short-term) memory skills.

In the above study there was a significant difference between the vocabulary performance of the top one-third of readers and the bottom one-third of the readers, even though all scores fell within the average range (Aguiar & Brady, 1991). The poorer readers showed phonological errors in new word learning, therefore their associated vocabulary difficulty may be phonologically related and the authors state: “the findings suggest that the vocabulary deficits of less-skilled readers stem, at least in part, from difficulty establishing accurate phonological representations for new words” (Aguiar & Brady, 1991, p.225). They concluded that poor readers have difficulty consolidating new vocabulary items into semantic memory.

Vallar and Baddeley (1984) investigated new word learning in an Italian-speaking subject with Down syndrome and associated intellectual impairment. Two sets of words were presented. Firstly, eight familiar Italian words were paired with eight unfamiliar Russian words (e.g. rosa-svieti). Secondly, semantically associated familiar words were paired. The subject was able to acquire all the unfamiliar Russian words in the set, but had greater difficulty than control subjects in recalling pairs of familiar words which were semantically linked. That is, her ability to learn new items was unimpaired, but recalling items linked by semantic association was impaired, a task requiring reasoning skills. This lends weight to the theory that phonological representations can be created independently of the semantic system (Vallar & Baddeley, 1987). The researchers concluded that the role of the phonological loop and PWM were more important in vocabulary acquisition than either semantic or cognitive abilities.

2.5.3 The Semantic System

Real word input passes from the phonological input lexicon to the semantic system for extraction of meaning stored from experience. Efficient and accurate semantic access is of course, critical for comprehension. In addition, the ‘richer’ the semantic representation, the more readily a word is recognised and understood (Rastle, 2007). Semantic processing for concrete items is bilaterally represented whereas current evidence suggests semantic processing for more abstract items occurs in the left hemisphere only (Binder, Westbury, McKiernan, Possing & Medler, 2005). It is thought that both word types are verbally represented in the left hemisphere, but concrete words are also imaged in the right hemisphere (Kounios & Holcomb, 1994). Consequently, interhemispheric transfer of information will be important during retrieval processes. In addition the linguistic ‘richness’ of representations in the left hemisphere may be critical for retrieval of abstract items.

The typical pathways for listening comprehension are shown in Figure 5 below. The figure shows verbal input entering the ear, passing to the temporal lobe and Wernicke’s area for phonological and linguistic processing then passing to Broca’s area and motor areas for mapping phonological output prior to production by the larynx. There is no evidence to suggest that the pathways are not the same in the APD population.

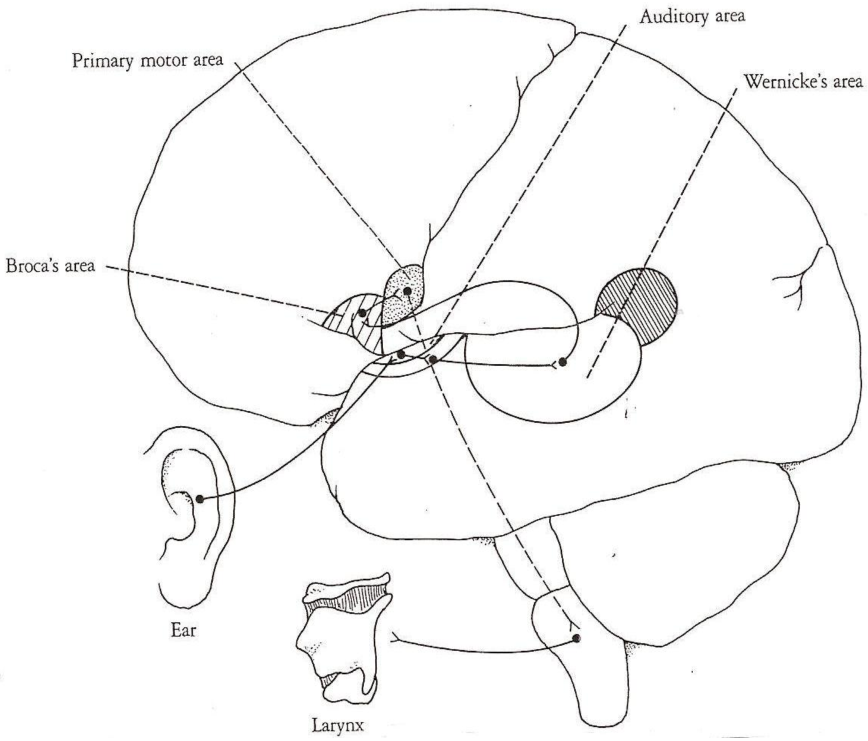


FIGURE 5:Typical left hemisphere neural pathways for responding to a spoken question[4] (Snell, 1987)

In an *f*MRI study of children aged 9 to 15 years Bitan et al. (2006) found evidence that phonology triggers semantic information. The participants had no history of language or literacy difficulty. The children were asked to decide whether 24 visually presented word pairs were firstly, spelt the same and secondly whether they rhymed. The rhyming tasks activated the bilateral inferior frontal gyri at Broca's area 45 and 47, indicating not only phonological (Broca's area 45) but also semantic involvement (Broca's area 47) that was not directly required for the task. This provides evidence that phonological information can automatically trigger semantic information, suggesting that poorer quality phonological information may therefore have an impact on the accuracy, quality and quantity of semantic information retrieved.

---

[4] (Snell, 1987, Clinical Neuroanatomy for Medical Students, Figure 15-6, p.293. Reprinted by permission of Lippincott Williams & Wilkins.)

The semantic system holds information about the meaning of the word and its associations to other known information. Inefficient access could result in any of the following observations in a listening comprehension task:

a) lost pieces of detail from information;
b) primacy effect i.e. earliest information only recalled;
c) recency effect i.e. later information only recalled;
d) difficulty recalling sequence of the information;
e) difficulty extracting most relevant information or main idea;
f) poor reasoning about the information e.g. inferencing, predicting what would happen next;
g) inability to summarise information

(Just & Carpenter, 1992).

Gleitman (1990) proposed the 'syntactic bootstrapping' theory of meaning extraction. By manipulating sentences to constrain the range of possible interpretations it is possible to investigate the ability to use syntactical information as a cue to word meaning. The example given by Gleitman is that the novel word 'gleep' would be understood as something being done to the ball in the sentence 'She gleeped the ball' whereas in the sentence 'She gleeped the ball to him', the word 'gleep' would be interpreted as a mode of transferring the ball from one person to another because of its position as a verb in the sentence in each case. The degree to which syntactic and semantic support is useful is dependent upon the strength of vocabulary and oral language skills.

Children with LI might be expected to have difficulty with the extraction of meaning of a novel word. This theory was investigated by (O'Hara & Johnston,

1997) who found the 6 to 9 year olds with LI (LI group: n = 6) were less accurate at extracting meaning using syntactic bootstrapping than children with normally developing language skills (NL group: n = 6). The children were provided with small toys and were asked to act out sentences containing a novel verb e.g. ‘the bunny *bims* the farmer and the cow’. However, closer analysis of their data suggested that the findings suggested a limitation of processing rather than a deficit in use of syntactical information. The children with LI appropriately understood the novel verb action in 69% of cases, but made errors in relation to other aspects of the sentence, such as choosing the wrong object or adding in an object. This led the researchers to investigate attention and short-term memory performance. The children with LI made three times the number of errors in relation to the initial object or medial object of the sentence than the final object. In comparison, these error types were too infrequent in the NL for any analysis. Though the sample size was small, this finding provides evidence for a PWM difficulty affecting comprehension to a larger extent than semantic or syntactic analysis.

Other possible theories for poor meaning extraction include difficulties interpreting cues from the environment or interpreting the intentions of others in the spoken exchange as to the possibilities of meaning. As previously mentioned, Aguiar and Brady (1991) established that IQ scores predicted semantic learning, suggesting that the cognitive ability to glean context for a new item may be an important factor. An earlier study by (Vellutino, Steger, Harding & Phillips, 1975) was able to demonstrate that reading disabled children (n = 30) were no less able to make associations between non-speech sounds (e.g. cough, hiss) and pictures than controls (n = 30) but were significantly less able to acquire nonword labels for pictures. The findings indicate that children with reading disabilities do not have a cognitive deficiency with making associations but a difficulty with phonological memory. When spoken auditory input is poorly defined, because of deficits in frequency discrimination, temporal sequence or separation from non-target input then auditory information will be either degraded or lost. The poorly defined speech enters the phonological store and the phonological loop, where conflict with multiple phonological representations occurs. The inefficiency experienced results in weakened PWM abilities. In turn, weakened PWM is detrimental to vocabulary development and its associated semantics, establishing impoverished language abilities.

Following the pathways shown in Figure 5, the poorly defined speech input may be incorrectly interpreted in the auditory cortex (Heschl's gyrus) and temporal association areas, responsible for interpretation of sounds (Snell, 1987). The information may not provide a sufficient phonological representation to activate existing semantic representations in Wernicke's area in the posterior temporal gyrus. Despite Wernicke's area being potentially intact, the language input cannot be properly understood, resulting in weak performance on listening comprehension assessments.

In summarising the literature, Brackenbury and Pye (2005) concluded that in the population with LI there was the strongest evidence of a difficulty holding phonological forms in the phonological loop and/or PWM and this was the most likely cause of poor vocabulary acquisition compared to the evidence for a difficulty perceiving and isolating the phonological form or extracting meaning from linguistic information. Of course, poor PWM would compound any difficulty extracting meaning from context as well providing an alternative explanation to the conclusions in the Aguiar and Brady (1991) study that meaning extraction was related to intellectual ability.

2.5.4 Relationship: Auditory Processing and Vocabulary

It is not repudiated that hearing impairment may cause significant delays in language development however, the effect of subtle auditory processing deficits has been more difficult to quantify (Tallal, 1980). Willeford (1985) summarised some of the problems surrounding the difficulties in drawing conclusions about the relationship between auditory processing skills and language as being due to at least the following factors:

- terminology confusion e.g. speech processing, speech perception, auditory perception, speech discrimination etc.;
- difficulty isolating specific auditory processing skills, free of all other variables;
- the complexity of language;
- the variety of AP testing methods used e.g. clicks, tones, speech segments, language.

Nevertheless, there are a couple of studies which have contributed to knowledge regarding auditory processing and vocabulary development, largely converging on the role of PWM (Metsala, 1999). Bishop (2002) reviewed a study conducted by the SLI consortium in 2002 and reported findings that individuals with specific language impairment (SLI) had both PWM deficits and auditory processing deficits as demonstrated by poor performance on a frequency discrimination task and a temporal resolution task. Using multiple regression analysis, Bishop (2002) found that the proportion of variance weighed in favour of a strong heritability link for PWM deficits, but that environmental factors weighed more heavily for auditory processing deficits. Environmental factors considered include parental occupation, parental education and family size. Bishop stated that “the simplest conclusion is that underlying impairments in auditory processing and phonological short-term memory act as additive risk factors for language impairment” and “…….it may be that language is such a robust human ability that it only becomes seriously impaired if more than one risk factor is present” (p.324). The findings also suggest that the presence of AP deficits may exacerbate PWM further or vice-versa, resulting in more severe language impairment.

In order to investigate the role of PWM in vocabulary acquisition, phonological short-term memory and PWM are evaluated via the repetition of number sequences (digit span), sentence recall and nonword repetition tasks (Gathercole & Baddeley, 1993). Metsala (1999) found moderate correlations between pseudoword (nonwords that resemble real words) repetition and vocabulary in 3 to 5 year olds. This level of significance held true for nonwords with a low resemblance to real words. Metsala also found a strong correlation between short-term memory on a digit span task and vocabulary as evaluated on the Peabody Picture Vocabulary Test- Revised. The scores from Gathercole and Baddeley’s Nonword Repetition Test have been consistently correlated with scores on standardised vocabulary measures with strong correlations at four years of age (r = 0.559), at five years of age (r = 0.524) and six years of age (r = 0.562), reducing by eight years of age (r = 0.284). Gathercole and Baddeley (1993) proposed that the ease by which new words are acquired is strongly linked to the adequacy of PWM. In a longitudinal study of children with average nonverbal intelligence and vocabulary ability, Gathercole et al. (1992) found that nonword repetition (PWM) was strongly correlated with vocabulary development at 4 , 5 and 6 years of age, but not at 8 years of age. Digit span also correlated with vocabulary at 6 and 8 years of age. Digit span was not tested in the younger groups in this study. In a further study of 70 children tested at 4 years of age and again at 5 years of age Gathercole (1995) found that the ability to repeat nonwords correlated significantly with receptive vocabulary in both the 4 year olds and the 5 year olds. Digit span testing was administered to the 4 year olds while the 5 year olds performed three tests of memory span including digit span and word repetition. Performance on the digit span measure correlated with the ability to repeat nonwords in the 4 year olds. Performance on the memory span tests also correlated with the ability to repeat nonwords in the 5 year olds. Further, there was a significant link between the nonword repetition scores of the younger children and later vocabulary performance and reading ability. The findings support the proposition that PWM underpins vocabulary acquisition and Gathercole et al. (1992) summarised thus:

> Specifically, we propose that children with good phonological memory abilities produce phonological memory traces that are highly discriminable and persistent and that, as a consequence, there is a greater probability for these children that any particular phonological trace will (a) become a long-term durable phonological trace and (b)

> link semantically with its referent. In theses ways phonological memory skills are seen as exerting a direct influence on the ease of acquiring a new vocabulary item. (p.895)

The role of PWM is most likely to be strongest in the early years of language learning when conceptual and lexical knowledge is low. In support of this Wagner et al. (1994a) found that in a large –scale longitudinal study of kindergarten to second grade students (n = 288) the developmental rate of PWM was comparable to the developmental rate of vocabulary performance. Baddeley et al. (1998) concluded that: “the fundamental mechanism linking phonological memory and vocabulary acquisition is the phonological store” (p.167). This relationship would be of greatest importance in the early years, prior to literacy education, when the individual is reliant upon auditory input for verbal learning.

It is known that poor readers consistently show weaker PWM abilities (Gathercole & Baddeley, 1993; Cain, Oakhill & Bryant, 2004; Gathercole, Pickering, Knight et al., 2004) and it is known that normally developing literacy experience has a positive impact on PWM ability (Stanovich, 1986; Aguiar & Brady, 1991; Vellutino et al., 2004). So it would seem that bringing weak PWM abilities to early literacy learning might be a risk factor for literacy difficulty, but literacy acquisition may help to develop PWM in the longer term. The literature thus far, assists our understanding of the directional flow of the factors involved in literacy outcomes and the current knowledge reinforces the importance of literacy intervention for less-skilled readers.

2.5.5 Co-morbidity: Auditory Processing and Language Impairment

PWM deficits have consistently been found in children with language impairments (Daneman & Carpenter, 1980; Gathercole & Baddeley, 1993; Montgomery, 2003). Norrelgen, Lacerda and Forssberg (2002) investigated auditory processing skills including temporal resolution, working memory and speech perception in children (age range: 5 to 7 years) with language impairment (n = 15) compared to controls (n = 99) and found no significant difference in temporal resolution skills, but a significant difference in PWM. However, these results must be viewed with caution due to the age of the children: Both groups had difficulty with the temporal resolution task, so it cannot be determined for certain that language impaired children do not have difficulty with temporal resolution tasks.

Wright et al. (1997) found evidence of auditory processing deficits in children diagnosed with specific language impairment (SLI) compared to controls matched for age and IQ. The small sample of children with SLI (n = 8) had significant difficulty detecting tones presented before, during and after masking noise. The children with SLI, unlike controls, had difficulty even when the tone was presented before the masking noise and had greatest difficulty when the tone was briefer and when the tone and noise were similar in frequency. It was concluded by Wright et al. that these deficits could affect speech discrimination. It would be reasonable to conclude that auditory deficits may not be at the core of all language impairments, but are present in a proportion of children with language impairment.

Bishop and McArthur (2005) also found that one third of individuals with SLI (n = 11; 10 to 18 years) had poor frequency discrimination and exhibited longer latency periods in event-related potentials (ERP) or brain stem responses compared to controls (n = 13). They observed that the frequency discrimination difficulties were present in the younger participants. However, at follow-up 18 months later those individuals with SLI showed improved frequency discrimination ability but ongoing delayed components of ERPs. The improvement in frequency discrimination ability is most likely a reflection of auditory system maturation. The inference, therefore is that delayed development of frequency discrimination abilities may have contributed to delayed language development in the early years in a subset of individuals with SLI (Bishop & McArthur, 2005).

A breakthrough finding by Wible et al. (2005) demonstrated that brainstem responses to the syllable /da/ in children with a mean age of 11 years 1 month were abnormal in about 25% of the children with LI (n = 11) compared to typically developing children (n = 9). This provides evidence linking AP abilities and LI. The findings lend weight to the proposition that AP deficits have an impact on the integrity of the information in the short-term phonological store within PWM.

For many years, it has been debated whether whole or part sentences are stored in PWM for linguistic analysis and whether PWM plays a role in listening comprehension at all (Baddeley & Wilson, 1988). Montgomery (2003) reviewed the literature on the relationship between PWM and SLI. Normally developing pre-schoolchildren have little difficulty repeating nonwords of up to two syllables, but performance with longer words decreases, depending upon PWM ability:

those with greater PWM capacity performing better than those with poorer PWM capacity. However, the question is whether this has any relationship to comprehension of word strings. The notion of functional working memory capacity (FWM) was introduced to refer to the PWM capacity that remains after resources are re-allocated from the phonological loop to long-term memory for linguistic processing i.e. a trade-off of capacity vs. processing. Children with SLI have been found to have comparable FWM to younger language-age matched children, but poorer compared to their age-matched peers (Montgomery, 2003). As expected, when testing the ability to comprehend ‘short’ vs. ‘long’ sentences, children with SLI were able to comprehend the same amount of short sentences as the language-age matched group, but fewer long sentences. There is emerging evidence that children with SLI have difficulty with rapid *storage* of large amounts of verbal information. This means that poor PWM in the SLI population may be due to the storage demands at the rehearsal stage of the phonological loop and not necessarily due to poor quality input from the phonological store.

A case study exploring this question was able to show that PV, an adult with impaired phonological loop function, had no disruption to articulatory function or auditory discrimination ability. Word length, phonological similarity and articulatory suppression effects on recall were absent. Comprehension of single words and sentences of up to seven words was unaffected (Vallar & Baddeley, 1984) while comprehension of longer sentences was impaired. Importantly for the present study, comprehension of both spoken and written sentential material was affected. A follow-up study confirmed that PV could understand the meaning of the longer sentences if the same information was condensed into a shorter sentence (Vallar & Baddeley, 1987). Based on PV’s ability to detect semantic and syntactic anomalies in longer sentences it was concluded that her comprehension was affected by diminished phonological short-term store influencing phonological loop function rather than linguistic difficulty. Her difficulty lay in remembering the sentences, not in understanding them. This is an important finding, confirming that PWM functioning and linguistic ability are inter-dependent yet separate systems. PV's language skills had developed while her phonological loop function was normal and remained so after impairment to the phonological loop. This means that a child with impaired phonological loop functioning does not necessarily have an impaired linguistic system, but the development and performance of that system may be affected as a consequence of obstructed rehearsal.

2.6 Word Reading Processes

Word reading is achieved via the orthographic input lexicon or the phonological route according to the PALPA model and the dual-route model. Under the BIA model and the connectionist model, word reading is displayed as a triangle with simultaneous orthographic, phonological *and* semantic contributions (Plaut et al., 1996; Frost & Ziegler, 2007).

2.6.1 Orthographic Input Lexicon

The *orthographic input lexicon* module is responsible for visual recognition of known words. Unfamiliar words and nonwords have no orthographic representation within the orthographic input lexicon. On the PALPA model, the orthographic input lexicon is preceded by the *abstract letter identification* module which represents the system for identifying letters (Kay et al., 1996). The word ‘abstract’ accounts for the ability of the visual system to encode the identity of letters in such a way that abstracts away from the actual visual features of the letter in order to accommodate font and case differences e.g. A, a or ɑ (Polk, Lacey, Nelson et al., 2009). It would seem to be logical that individual letters must be recognised prior to the word entering the orthographic input lexicon (Kay et al., 1996).

2.6.1.1 Word recognition and identification

The recognition aspect of identifying objects, pictures, letters, numbers and words is usually referred to in the literature as visual recognition or direct visual access. The production or naming aspect of identification is referred to as rapid naming, naming speed, rapid automatized naming, rapid automatic naming (RAN) or simply, naming. In the process of reading, all these terms refer to the ability to label a letter, number or word aloud. RAN abilities are important in reading research and have been shown to be a powerful predictor of not only oral expression but also reading fluency and reading comprehension (Felton & Wood, 1989; Lyon, 1999). For the purposes of this study, word recognition refers to the input process and naming refers to the word being read aloud. Word identification is the combination of recognition and naming.

Rapid identification of a written word requires firstly, attention to the visual stimulus, followed by visual analysis, comparison with long-term memory storage for both visual and phonological recognition and matching processes plus optional semantic retrieval. Recognition reactivates the phonological representation and then optionally (at word level), the semantic representations of the word stored in long-term memory. When the word is to be read aloud then retrieval of the phonological map is necessary and finally a motor response to articulate the spoken word (Gough & Tunmer, 1986; McGuiness, 2005). The complex series of cognitive processes involved in recognising and naming a word normally takes 500-600ms (Glushko, 1979; Wolf et al., 2000) in a fluent reader.

The rapidity of word identification is a major difference between good and poor readers (Share, 1995). Vellutino et al. (1995) investigated a group of ‘poor’ readers in second ($n = 15$) and sixth grade ($n = 15$) and compared their performance to age-matched normal readers ($n = 30$) on naming tasks. Second grade ‘poor’ readers scored ≥ 1 year below chronological age on reading ability and the sixth grade ‘poor’ readers scored ≥ 2 years below chronological age on reading ability. Poor readers performed at a significantly lower level at both grade levels. For both groups letters could be named more rapidly than either objects or colours. Interestingly sets of letters which rhymed (e.g. c, p, t, v, b) were more rapidly named than non-rhyming sets (e.g. b, m, j, r, y) (Vellutino et al., 1995). It is suggested that this occurs because the motor articulation subprogramme for the ‘rime’ part of the word has already been activated or primed (Gathercole & Baddeley, 1993).

Visual word form activation and semantic activation follow abstract letter identification during word recognition. Ideal visual fixation on a written word is between the beginning and the middle of the word rather than beginning of the word because this position brings the final letter in the word closer and is the most highly informative part of word for both meaning and phonology. This ideal fixation point is referred to as the optimal viewing position (OVP). When the OVP is manipulated to the left or right within the word, word identification is significantly affected (Brysbaert & Nazir, 2005). In text reading, proficient readers glimpse the beginning of the upcoming (parafoveal) word (Brysbaert & Nazir, 2005) during saccadic eye movements and it is highly likely that this would assist recognition of that parafoveal word. Normal saccadic eye movements during reading shift 24% to the left and 76% to the right (New, Ferrand, Pallier & Brysbaert, 2006) of the fixation point. The visual word form area or VWFA located in the left occipito-temporal sulcus area is always activated during word recognition tasks (Price, Thierry & Griffiths, 2005).

A number of factors have been identified as having an impact on rapid word recognition. These include the following factors which are subsequently expanded:

a) age of acquisition
b) frequency of exposure
c) regularity

d) word length
e) imageability

a) Ghyselinck, Custers and Brysbaert (2004) found that words acquired at an earlier age were recognised more rapidly than later acquired words. This age of acquisition effect is thought to occur because of the central position that early recognised words occupy in the semantic network, resulting in more semantic connections overall than word acquired later (Brysbaert, Wijnendaele & De Deyne, 2000). This effect has been demonstrated by a semantically associated word being provided significantly more rapidly by first-year university students (n = 21) for early acquired words than later acquired words.

b) High frequency words are considered to have a perpetual resting level of activation requiring less evidence from input to reach the threshold of recognition (Coltheart et al., 2001). Share (1995) proposed that every successful decoding attempt builds orthographic recognition and the more rapidly and expansively that this occurs, the sooner the reader becomes proficient. This places importance on reading exposure. Supporting this position, Lyon (1998) has stated that the average reader requires between four and fourteen exposures to a new word for that word to become automatically recognised. As a consequence of frequency of exposure, high frequency words are read aloud more rapidly than low frequency words and nonwords (Coltheart et al., 2001).

c) Words which represent a regular letter to sound relationship (e.g. catnip) are read aloud more rapidly than irregular words (e.g. draught) (Coltheart et al., 2001)

d) Word length research has yielded some interesting findings. Words of 5 to 8 letters in length are recognised more rapidly than words of either 3 to 5 letters or 8 to 13 letters in length (New et al., 2006). There are at least two possible reasons for this. Firstly, it is more difficult to visually eliminate confusion with adjacent words in text when the word is short, whereas a word of 5 to 8 letters is an ideal length to contain the normal range of saccadic eye movements left and right, possibly encapsulating the beginning of the upcoming word also. Secondly, many words of 3 to 5 letters have numerous orthographic neighbours e.g. cat- cot, cut etc. than words of greater length (New et al., 2006). In addition, each additional syllable beyond a bisyllabic word adds about 20 milliseconds to recognition time and this is referred to as the syllable length effect (New et al., 2006).

e) Studies have shown that imageability of words influences word recognition in both dyslexic and normal readers (Strain, Patterson & Seidenberg, 1995; Nation & Snowling, 1998a, 1998b). This may go some way to explain why dyslexic readers have great difficulty with low imageability words e.g. ‘for’, ‘what’, ‘was’. The study by Brysbaert et al. (2000) demonstrated that high imageability (Dutch) words were recognised significantly more rapidly by first-year university students (n =

21) than low imageability (Dutch) words. As previously mentioned, imageable words are bilaterally represented at the cortical level whereas abstract items are represented in the left hemisphere only (Kounios & Holcomb, 1994; Binder et al., 2005). Undoubtedly, vocabulary development and both listening and reading comprehension benefit from the imageability of the information being conveyed, though a full discussion is beyond the scope of this paper.

2.6.1.2 Naming

Impaired object-naming has been observed in children as young as three years of age who were later diagnosed with dyslexia (Scarborough, 1990). These difficulties remained at 5 years of age. Poor letter naming was also a striking feature in children at 3 years 9 months and at 6 years who were later diagnosed with dyslexia in the study by Gallagher, Frith and Snowling (2000). According to Wolf *et al*. (2000) normal readers achieve automatic letter naming between Grade 1 and 2 level while readers with dyslexia remain impaired. LSR generally approximate normal readers at this age and naming speed is a weaker predictor of later reading in this population than for readers with dyslexia (Wolf et al., 2000). This appears to conflict with the findings of studies that have found naming difficulties in 'poor' readers e.g. Vellutino's (1995) study mentioned in the previous section. It is likely that the samples of 'poor' readers contained some subjects with dyslexia.

Wolf *et al.* (2000) have researched naming speed in great depth and while they acknowledge that phonological processes play a role in word recognition, this is only one of many processes employed when rapid recognition is required. Instead of poor naming being viewed as the result of poor phonological retrieval they conclude that naming relies upon a number of factors including visual feature and visual pattern analysis prior to integration with the phonological representation and activation of semantic representations (Wolf & Bowers, 1999). Interference theories add that retrieval of names relies upon efficient inhibition of distracting similar visual associations as well as the motivation to maintain seeking the target name in spite of competitive intrusions to that goal (Anderson, 2003).

Bowers, Steffy and Tate (1988) investigated the differences between ‘reading-disabled’ readers who scored below the 25th percentile on the Woodcock-Johnston Letter Identification, Word Identification and Word Attack subtests (n = 22) and ‘normal’ readers who were referred to their clinic due to learning difficulties but who scored above the 25th percentile on the same test cluster (n = 24) in the 8 to 11 year age group. When performance IQ was controlled, disabled readers differed from ‘normal’ readers on measures of RAN, digit span and sentence recall. However, when verbal IQ was controlled, the disabled readers differed on performance on RAN tasks only (Bowers et al., 1988). Therefore, when performance IQ is controlled, readers with low verbal IQ are not separated out. It can be extrapolated that it is the readers with some degree of language difficulty who are simultaneously experiencing difficulty with short-term memory for digits and sentences. Those readers experiencing naming difficulty are more likely to be dyslexic and this is supported by Bishop et al.’s (2009) finding that naming was the strongest predictor of dyslexia on discriminant function analysis of reading related variables.

2.6.1.3 Relationship: Auditory processing and naming

Naming speed has often been thought to have a phonological basis (Shankweiler, 1989) yet the correlations between phonological ability and rapid naming have not been strong (Wagner & Torgesen, 1987; Wolf et al., 2000). It is argued that many individuals with phonological deficits do not have naming speed deficits. Wolf (1986) proposed a deficit in orthographic analysis as possibly being attributed to a weakened ability to make rapid visual discriminations. Some neurophysiological evidence was provided by Galaburda, Menard and Rosen (1994) who found that neurones within the magnocellular system within the lateral geniculate nucleus were aberrant in function. These cells are considered to be important in the processing of transient visual information, thus affecting visual analysis of letters and words. However, since that time, Wolf et al. (1999; 2000) have acknowledged that naming speed is most likely the sum of a range of processes involving attention, perception, memory, phonology, semantics and motor systems, undoubtedly involving integration areas between these systems.

Phonological representation theory (Stanovich, 1993) suggests that naming speed difficulties occur when the individual has difficulty converting speech or written input into the phonological code in the presence of an intact auditory system. Without efficient activation of the code the individual does not have a phonological representation available for working memory (Mody et al., 1997). Without this, the meaning of the input cannot be extracted and may be lost altogether. Readers with dyslexia seem to have particular difficulty with symbolic representation of phonological information.

Wile and Borowsky (2004) proposed that by using measures whereby the individual must name the sounds of the letters rather than the names of the letters presented would tap phonological representation more effectively. Ideally, using both procedures allows a comparison of ability across procedures. This is incorporated in many tests of phonological awareness. Johnston and Anderson (1998) found that poor readers demonstrate a delayed response time compared to chronologically age-matched controls when labelling pictures, suggesting difficulties with retrieval of phonological representations from long-term memory. McNeil and Johnston (2004) proposed that: “poor readers may therefore have underspecified phonological representations for printed words in long-term memory and/or experience difficulty in accessing the information in long-term memory” (p. 693).

2.6.2 Decoding Print

While naming speed aims to account for difficulty reading via the ‘direct’ visual route, the efficiency of the ‘indirect’ phonological route also has an impact on word identification. To this end, Gathercole and Baddeley (1993) stated that: “the information processing procedures that are necessarily involved in 1) the indirect route to reading and 2) the recoding of visual information into the phonological loop have not gone unnoted” (181).

Their statement above refers to the cross-modal nature of 1) converting letters to sounds via the indirect route and 2) converting words (and pictures) to their phonological map via the direct route in a naming task. Both tasks require visual analysis to activate phonological retrieval. Intervention methods such as Letterland^{TM} (Wendon, 2003) or Jolly Phonics^{TM} (Lloyd, 1998) have been successful because of the emphasis on visual analysis while simultaneously enriching the connection between the visual features of letters and the corresponding phonology by embedding the sound within a semantic framework related to the letter character e.g. d/D = "Dippy Duck says 'd' in words" (Stuart, 1999; Coltheart, 2005). Such programs assist the child to view letters as 'pictures of sounds'.

Decoding is a frequently misinterpreted term. Sometimes it refers to word recognition i.e. ease or speed of word identification as accepted by some researchers (Shankweiler, 1989) and other times to the act of 'cracking' the sound code of the word as accepted by other researchers (Gough & Tunmer, 1986). The former is more correctly referred to as naming and the latter as decoding. In fact, deciphering the alphabetic system would be even more correct. A code indicates a hidden message accessible only to those who know the code, whereas written English is a symbolic representation of sounds and therefore, a cipher. However, the term decoding is in common use and will be continued here. Once the code is understood, this is referred to as acquisition of the alphabetic principle and the reader can now use the code to sound out unfamiliar words. However, a complication arises when the code is correctly applied but does not match with the target word e.g. accurate sounding of each letter in 's-w-o-r-d' will not blend the target word ‘sword’. It might be argued that the reader has poor orthographic knowledge or immature decoding.

Share (1995) proposed that successful readers *recode* their previously limited 1:1 letter-to-sound decoding to more advanced levels of decoding. In the upcoming example the individual letters ‘o’ and ‘r’ are recoded as a visual chunk (digraph) corresponding to the vowel sound ‘or’ as in ‘f-or-k’ and ‘s’ and ‘w’ are recoded as ‘s’, with a silent ‘w’ for ‘sword’. With increasing orthographic knowledge, larger chunks of orthographic information are phonologically recoded, moving towards whole word or lexical recoding. Using semantic context as well orthographic knowledge advances each time this is successful. As a consequence, word recognition abilities advance. Gough and Tunmer (1986) agree with this position, and state that 1:1 sounding is simply primitive decoding and that more highly developed word recognition uses more advanced orthographic decoding, applying the consistent rules of the code e.g. that ‘ph’ makes the ‘f’ sound or ‘augh’ makes the ‘aw’ sound etc. In English orthography a four letter series may represent only two sounds e.g. ‘dgew’ in ‘bridgework’ i.e. ‘j’ plus ‘w’. This important stage of recoding previous knowledge is assumed to be very taxing on PWM during the reading process (Gough & Tunmer, 1986; Gathercole & Baddeley, 1993). Imagine being confronted with the Welsh word ‘cwrw’ for the first time. This word violates the rules of English orthography. Yet once you learn to recode ‘w’ as ‘oo’ you can read it accurately as ‘koo-roo’(Bryson, 1990). However, the first time you encounter multiple examples of this new orthography in text extra demands are being placed on PWM as conflicting phonological options for ‘w’ are activated. Poor PWM hinders letter-sound learning, particularly beyond 1:1 correspondences, despite phonological awareness abilities being potentially intact. Poor PWM also hinders sound blending, especially maintenance of correct sound sequences that exceed PWM capabilities. As a consequence, segments of target words may be decoded in a developmentally earlier manner using accurate1:1 correspondence, but this may not correspond with the digraphs or trigraphs in the word e.g.'welfar' for 'welfare' or 'ponted' for 'pointed'. The sounds of longer, multisyllabic words may be blended out of sequence or with additions and omissions e.g. 'evanced' for 'advanced' or 'servised' for 'supervised'. Lack of success may lead to seeking alternative strategies for word reading using available visual or semantic information. Only when all the orthographic rules of the English language are acquired can proficient decoders read any word or nonword that obeys those rules.

2.6.2.1 Phonological awareness acquisition

Phonological awareness encompasses metalinguistics skills with the ability to segment words into individual phonemes or sound units as the ultimate aim. A large body of literature attests that phonological awareness and phonological short-term memory deficits are at the core of the majority of reading deficits (Bradley & Bryant, 1983; Lundberg et al., 1988; Shankweiler, 1989; Lenchner, Gerber & Routh, 1990; Catts, 1991a; Stanovich, 1993; Swank & Catts, 1994; Muter et al., 1997; Stackhouse, 2000). The development of strong phonological awareness plays a crucial role in early reading success. The high degree of consistency in the findings has led to the assumption of a strong relationship between phonological awareness and early literacy.

The sequence of normal phonological awareness acquisition is remarkably similar across different languages (Goswami, 2002). In order to acquire competent phonological awareness the child must be able to make the subtle acoustic discriminations of phonemes within syllables. This enables the segmentation of words and syllables into individual phonemes. This understanding is necessary before a child can comprehend the association of sounds to the letters that represent them. In English, the 45 phonemes are represented by more than a hundred permutations of the 26 letters of the alphabet.

There are differing theories on how the ability to segment phonemes is achieved. The 'accessibility' theory states that the development of the phoneme as a psychological unit is necessary for speech processing and under this theory, a child needs to develop an awareness of the existence of phonemes within the word as a metacognitive skill (Metsala, 1999). That is, the child must be able to 'pull out' or segment individual sounds from the word. This is usually achieved initially through rhyming tasks where one phoneme or 'sound' is altered in the creation of rhyming words and through tasks which break words into the individual phonemes e.g. "What sound does 'sun' start with?" It is assumed that performance will be better if the targeted word is stored in long-term memory and is highly familiar. Metsala (1999) was able to demonstrate that performance was higher on phonological awareness tasks containing familiar words rather than nonwords. Metsala adds that performance is also higher when a word has a high neighbourhood density e.g. 'cat' vs. 'hat', 'fat' etc. Metsala (1995) describes two words as having high neighbourhood density when they differ by one phoneme or in the case of orthography, by one letter.

The alternative ‘emergent’ theory proposes that phonological awareness arises out of vocabulary development. The phoneme develops as a psychological unit as the child has to discriminate between words with high neighbourhood density e.g. ‘duck’ and ‘dug’ or ‘fall’ and ‘wall’ (Metsala, 1999). This process of auditorily discriminating speech sounds is sometimes referred to in the literature as phonological acoustical analysis, phonetic encoding, speech perception, speech discrimination or auditory discrimination. From the whole word, the child ‘discovers’ its component parts. Rhyming exposure facilitates this process. Hence, the ‘emergent’ theory provides a plausible link between auditory processing, vocabulary development and the development of phonological awareness skills.

2.6.2.2 Phonological awareness and literacy

To examine the relative contribution of phonological awareness to reading Fletcher (1994) performed multiple regression analysis of nine variables related to reading skill in children (n = 199; age range: 7;5 to 9;5). The nine variables included verbal ability, non-verbal ability, visuo-spatial tasks, speech production, rapid naming and phonological awareness. Of all the tasks, phonological awareness ability had the greatest contribution to reading ability.

The link between the sound categorisation skills (identifying initial phonemes in words) and later reading achievement was so strong in 4 and 5 year olds tested (n = 403; r = 0.57) that their finding led Bradley and Bryant (1983) to conclude that the skills were causally linked. After reviewing whether phonological awareness was a prerequisite of reading, a facilitator of reading, a consequence of reading or a correlate of reading, Wagner and Torgesen (1987) and Lundberg et al. (1988) also supported the causal relationship between phonological awareness skills and reading development. A further example was provided by Scarborough (1990) who found a significant difference between the phonological awareness abilities on rhyme matching and first-sound matching tasks of 5-year-old children who were later diagnosed with dyslexia (n = 20) compared to 5-year old controls who became normal readers (n = 20). Swank and Catts (1994) found that measures of phonological awareness ability could predict reading ability in the first year of school with 80-90% accuracy. An important finding by Wagner et al. (1994a) was that phoneme analysis skills at pre-school age were strongly correlated with reading skill in first grade (r = 0.75) but not between first grade and second grade (r = 0.19), when actual reading skills at first grade became the strongest predictor of reading ability in second grade, suggesting that skills other than phoneme awareness become more important. The relationship between phonological awareness and reading development is still debated and many prefer to modify the link to a predictive rather than causal status (Castles & Coltheart, 2004). The existence of this debate is itself is an indicator of the accepted importance of the relationship between phonological awareness and literacy.

Phonological awareness skills are highly responsive to training (Lundberg et al., 1988; Gillon & Dodd, 1995; Mallen, 1996). Children who participate in phonological awareness intervention programs consistently outperform control groups in their later literacy attainment (Lundberg et al., 1988). Lundberg et al. (1988) showed that the ability to segment phonemes required the most explicit training yet had the greatest impact on later literacy achievement. In a study by

Borstrøm and Elbro (1997) a phonological stimulation program was implemented with preschool children (n = 36) of parents known to have dyslexia. In large population samples, heritability would predict that at the very least 40% of children born to a parent with dyslexia will also be diagnosed with dyslexia. Following phonological awareness stimulation training only 17% of the children in Borstrøm and Elbro's study were later diagnosed with dyslexia. Significant gains were made in letter naming ability, word reading and phoneme deletion tasks in particular. Torgesen et al. (1994) caution that there is individual variation in responsiveness to phonological awareness training and therefore, while it is a vital component of pre-literate teaching, it cannot be assumed that exposure to training will be sufficient for reading development to occur. To reinforce this, Castles, Coltheart, Wilson, Valpied and Wedgwood (2009) have shown that neither phoneme awareness nor letter exposure are sufficient to ensure reading acquisition unless letter-sound correspondence tasks make the link explicit.

PWM may also play a critical role in the decoding of print to phonology when reading aloud (Gathercole, 1995). It has been proposed that this may be most important in the early years of reading when letter-sound correspondences occur slowly and serially rather than automatically in a parallel manner (Xavier-Alario, De Cara & Ziegler, 2006). However, this was not supported by the longitudinal findings of Oakhill et al. (2003) who found a moderate correlation between PWM (word and sentence memory) and the reading accuracy measure on the Neale Analysis of Reading Ability –Revised (Neale, 1989) at 8 to 9 years of age but not at 7 to 8 years of age. It is possible that this reflects the length of the words being decoded by the higher age group, demanding greater PWM during the decoding process.

2.6.2.3 The strongest phonological predictor of literacy success

As previously stated, the aim of phonological awareness development is to achieve phonemic (or sound) segmentation skill in preparation for sound-letter correspondence. Sound segmentation is the skill that is often considered to be the strongest predictor of literacy success at the end of the first year at school (Muter et al., 1997; Stein & Talcott, 1999). Earlier, Bradley and Bryant (1983) emphasised the predictive capabilities of rhyming to literacy success. Both findings are correct but rhyming is a precursor to the sound segmentation task. Recognising rhyme requires the listener to identify that the final part (rime) of the word matches across two or more words, but the first phoneme (onset) is different. Rhyme generation requires separation of the onset from the rime and replacement with another onset to create a rhyming word e.g. ‘wall’ becomes ‘fall’. Syllable segmentation and blending tasks have *not* been strongly correlated with literacy success (Lundberg et al., 1988) nor have they been found to demonstrate a developmental pattern (Mallen, 1998). It is argued by some, that sound segmentation is not achievable until the child has been exposed to letters or at least is greatly facilitated by exposure to letters (Ball, 1997; Goswami, 2002). This is not supported by the findings of Lundberg et al. (1988) or (Yopp, 1992) who conducted studies with pre-literate pre-school children who were able to achieve successful initial sound segmentation and sound segmentation of simple words prior to letter exposure.

Phoneme deletion tasks have been found to strongly correlate with reading accuracy. A phoneme deletion task requires the participant to say a word, but delete one phoneme, at varying levels of difficulty e.g. “say ‘lamp’ without the ‘m’”. In a longitudinal study Oakhill et al. (2003) found that phoneme deletion ability was moderately correlated with reading accuracy on the Neale Analysis of Reading Ability (Neale, 1989) in unselected children at 7 to 8 years of age and again at 8 to 9 years of age. Phoneme deletion requires both sound segmentation and PWM for the sound manipulation component.

It has been suggested that sound-letter correspondence is in fact the strongest predictor of literacy success (Elbro et al., 1998; Gallagher et al., 2000). Sound segmentation is a precursor to this skill: successful sound-letter correspondence develops later and is therefore, functionally closer to the reading task (Share, 1995). Taking it one step further, (Wagner et al., 1994a) found that sound blending (or synthesis) influenced reading performance in second grade more than sound segmentation. Again, sound-letter correspondence is the pre-cursor for this skill. Consequently, each of these skills of rhyming, sound segmentation, sound-letter correspondence and sound blending has predictive value for reading proficiency, depending on the age of the child and the stage of literacy development.

Phonological awareness training in the pre-literacy stage will increase the child’s chance of success with the sound-letter conversion task (Catts, 1991b; Torgesen et al., 1994; Elbro et al., 1998). However, once letters are introduced, visual analysis becomes important and the task becomes cross-modal (Wolf et al., 2000). The visual information received must be converted into the phonological code when reading aloud, but de Jong, Bitter, van Setten and Marinus (2009) have also been able to show that unfamiliar words are phonologically mediated even during silent reading in children aged 7 years 7 months to 8 years 11 months (n = 56). This was established by determining that the naming speed of re-presentation of target items was significantly faster compared to newly presented items, indicating that phonological decoding and mediation had occurred.

Evaluation of letter-sound correspondence skills is frequently performed via nonword reading tasks, often called word attack skills. Nonword reading tasks assess letter-sound correspondence without interference from familiar words stored in long-term memory. Nonword reading tasks have been widely used in research studies of LSR and readers with dyslexia. Nonword reading is known to be impaired in both less-skilled and readers with dyslexia (Vellutino et al., 1995; Coltheart & Leahy, 1996; Snowling, 2000a). Vellutino et al. (1995) found that poor readers performed at a significantly poorer level than normal readers on nonword reading tasks in both second and sixth grade. Both the nonword reading ability effect and grade effect were significant, with greater difference at second grade than sixth grade.

Rapid letter-sound conversion allows the reader to produce an unfamiliar real word encountered in text and therefore to predict its meaning from the context, thus also contributing to vocabulary development. The act of reading therefore enhances vocabulary development and reading comprehension (Vellutino et al., 1995). Reading experience further enhances phonological awareness development as well, resulting in the reciprocal relationship often referred to as the ‘Matthew effect’ whereby good readers improve exponentially while less-skilled readers fall further behind. The exegesis is in the Gospel according to Matthew (XXV:29) stating: “For unto everyone that hath, shall be given, and he shall have abundance; but from him that hath not shall be taken away even that which he hath" (Stanovich, 1986, p. 381). The unsuccessful reader cannot make best use of the current year level curriculum and even if he or she catches up with the work, the class has moved on, resulting in a demotivated state.

Continuing improved phonological awareness skills ensure increasing reading accuracy and vice-versa. Strong phonological awareness abilities also assist the transition of a word towards the lexical route via more rapid word recognition thus contributing to reading fluency (Catts, 1991b). Contrary to popular view, good readers rely less on context for word prediction than poor readers because they are able to achieve rapid rates of word identification. Ease of identification uses less structural capacity, leaving more capacity available for higher linguistic processing post-identification. That is, context does aid comprehension in good readers, but has less effect on word identification than one might expect (Stanovich, 1986). The same applies, in Stanovich's view, to the visual processing aspects of word recognition in good readers. Little attentional capacity is required for visual recognition in good readers, but this is not because it isn't important in reading, but because it happens easily for them.

Lundberg (2002) cautioned that the predictive ability of early phonological awareness skills may be significant for the early stages of reading development and that language factors may be better predictors of long-term reading ability. This supports the notion that phonological awareness skills are necessary but not sufficient for the acquisition of competent reading in the long-term. At the very least it is likely that the importance of phonological awareness in long-term reading outcomes may be developmentally limited. A longitudinal study by Catts, Fey, Zhang and Tomblin (2001) tracked 604 students from kindergarten to second grade. They found that a combined measure of letter identification, sentence recall, phonological awareness ability (based on a sound deletion task), rapid naming and maternal education calculated in kindergarten uniquely predicted the probability of reading difficulties in second grade with 93.3% accuracy. However, even stronger predictions have been made from early reading achievement and in particular, letter-sound correspondence alone once formal reading instruction had commenced (Tunmer, 1994). In summary, phonological awareness plays a crucial role in preparing the pre-literate child for the acquisition of efficient sound-letter correspondences and ultimately, rapid decoding.

2.6.2.4 Relationship: Auditory processing and phonological awareness

Phonological processing deficits are a feature of both dyslexic readers and LSR. Despite the close association between PWM and reading achievement, there is no direct evidence that weak PWM affects phonological awareness development (Gathercole & Baddeley, 1993). For instance, Bradley and Bryant (1983) were unable to demonstrate an association between rhyming ability and PWM. Hull (1999) investigated the phonological abilities of students aged 7 and 10 years and diagnosed with APD. Phonological abilities were measured by binaural separation tasks and auditory short-term memory tasks. She found that not all students with a diagnosis of APD were experiencing phonological awareness difficulty, though they did exhibit difficulties with PWM and auditory discrimination in noise.

Gathercole and Baddeley (1993) have investigated the apparent disassociation between PWM and phonological awareness that exists despite the clear contribution that both make to reading ability. They propose that it is at the point of letter-sound correspondence that the two skills combine. Phonological awareness is critical for understanding the segmented nature of words into individual sounds, but PWM is required to learn the associations between letters and sounds, referred to as phonological learning. Letter-sound associations are initially learnt as 1:1 relationships e.g. letter 'c' says 'k', but are then recoded in order to acquire more complex orthography e.g. 'augh' says 'or'. Recoding requires an understanding of the letter-sound relationship but also strong PWM skills, especially in the application of this new learning to decoding written words. During word or text reading, unrecognised words must be either 'substituted/guessed' or segmented into letter-sound units, held in the phonological loop and blended together to form the whole word.

2.6.3 Summary of Word Reading Processes

Word identification can be achieved via the orthographic or phonological route. Identification involves firstly, recognition and when reading aloud, naming. To summarise word identification via the *orthographic input lexicon* on the PALPA model the following research has been outlined:

- word recognition and naming abilities are a predictor of reading fluency and comprehension (Felton & Wood, 1989) and distinguish ‘good’ compared to ‘poor’ readers (Share, 1995);
- the first stage is abstract letter identification (Kay et al., 1996; Polk et al., 2009);
- secondly, optimal visual fixation is placed between the beginning and middle of the word to promote visual word form activation (Brysbaert & Nazir, 2005);
- thirdly, when visual word form activation (and/or phonological input when using the phonological route) reaches threshold, semantic activation takes place (Coltheart et al., 2001);
- words acquired at an early age are recognised more rapidly (Ghyselink et al., 2004);
- higher frequency of exposure primes more rapid recognition (Share,1995);
- words of 5 to 8 letters are recognised more rapidly than shorter or longer words (New et al., 2006);
- imageability of words influences word recognition (Brysbaert et al., 2000);
- impaired naming ability is consistently found in the dyslexic population (Snowling, 2000);
- some researchers conclude that phonological deficits are at the core of naming difficulties (Katz, 1996);
- other researchers conclude that naming speed is a function of orthographic, phonological, language and retrieval processes (Wolf & Bowers, 1999);

- other proposals include cross-modal difficulty converting written input into phonological representations (Stanovich, 1993).

To summarise the investigations regarding the effect of auditory processing abilities upon phonological awareness, speech discrimination and language processing the following research has been outlined:

- of nine reading-related variables, phonological awareness makes the greatest contribution to reading ability (Fletcher, 1994) particularly in tasks requiring PWM (Gathercole, 1993)
- the purpose of phonological awareness is to achieve sound segmentation skill in preparation for sound-letter correspondence, necessary for efficient word decoding (Torgesen et al., 1994)
- phonological awareness skills may be more important in the early stages of reading development and language factors may be better predictors of long-term reading ability (Lundberg, 2002)
- phonological awareness and PWM combine at the point of letter-sound correspondence learning (Gathercole & Baddeley, 1993)
- recoding 1:1 letter-sound correspondences towards more advanced decoding of letter chunks requires an understanding of the letter-sound relationship but also strong PWM skills, especially in the application of this new learning to decoding written words (Gathercole, 2007)

Ramus et al. (2003) also proposed that possibly auditory processing deficits may also impose an upper limit on the development of phonological skills.

2.6.4 Word Reading Errors

Accepting the simple view of reading (R = D x C) where R is reading, D is decoding and C is comprehension, there are only three types of reading difficulty: difficulty with decoding, difficulty with comprehension or both. Tests of nonword reading and single word reading are tests of decoding ability in the absence of any psycholinguistic, pictorial or contextual cues. During these tasks, the letter-sound correspondence task may be disrupted by visual processes such as letters reversals, alterations to letter sequences or substitutions based on the overall shape of the word e.g. ‘place’ for ‘palace’. Unrecognised words must be substituted by another word, refused or segmented into sounds and blended. The segmented phonological units are held in the phonological loop until blending of the whole word (or the attempt at the whole word) has been completed. Blending, in particular is therefore problematic in the presence of PWM deficits. Blending errors occur that may include sound deletions, sound additions, sequencing errors, sound substitutions or whole word substitutions for phonologically similar words (Goulandris, 1996). There have been numerous systems of classifying reading errors, some of which will be outlined here.

Most error analysis systems include separate visual and phonological categories. For instance, Felton and Wood (1989) used a simple classification system that exemplifies this. They classified readers according to their reading errors as normal, nonspecific, dysphonetic (phonological errors), dyseidetic (visual errors) or mixed. Goulandris (1996) devised a reading error analysis with five error types: two types of visual errors (few vs. many shared letters e.g. ‘beard’ for ‘bread’), regularization errors (mispronouncing the word according to 1:1 letter-sound correspondence), unsuccessful sound attempts (decoding) and partial phonological access (partially correct decoding). An additional category was also included for refusals and miscellaneous errors.

McGuiness(1997) devised a system categorising reading errors as either probable (legal) or improbable (illegal) in their phonetic structure. Examples of illegal phonetics are ‘sheep’ read as ‘seep’ or ‘time’ read as ‘Tim’. An example of a legal error is ‘great’ read as ‘greet’ because the ‘ea’ orthography frequently makes an ‘ee’ sound. Errors of first graders (n = 39) and reduced sample of the same children as third graders (n = 31) were also grouped according to whether they affected part of the word or the whole word. Error type was strongly correlated with their current reading ability and strategies used as first graders predicted 30-37% of the variance in word recognition in third grade. For instance, whole word errors were negatively correlated with reading ability while part word errors were positively correlated with reading ability. One of the earliest decoding strategies (of an unfamiliar word) is to perform 1:1 letter-sound conversion of the first letter only and guess the remainder of the word, possibly using some cues from word shape and length and possibly context e.g. ‘hat’ for ‘head’. By the end of the first year, recoding occurs with larger chunks of letters being decoded e.g. ‘sh’, ‘ing’ etc. As mentioned previously, recoding of some individual letters into letter chunks is an important development, that requires strong PWM (Gough & Tunmer, 1986; Gathercole & Baddeley, 1993). As reading becomes better developed an increasing use of analogy from known words e.g. familiar word ‘caught’ to assist unfamiliar word ‘taught’ (Frith, 1986) has been observed. While

Frith placed a high degree of importance on the development of analogy, McGuiness (1997) questioned this conclusion as she found little evidence of analogy as a cause of reading errors, and where it did occur, could equally be explained as a decoding error e.g. if ‘great’ is read as ‘greet’ it could be because of analogy to the word ‘treat’ but equally application of the legal conversion of ‘ea’ to ‘ee’. Another strategy shift from whole word errors to part word errors was observed when the first and third grade reading errors were compared, indicating improved decoding efficiency overall. Of concern, about one third of children did not develop more efficient strategies over this time period, supporting the contention by Stanovich (1986) that poor readers at first grade tend to remain poor readers if they do not receive remediation. While the system of legal and illegal phonetics has usefulness in evaluating decoding it is not useful as a comprehensive analysis of all error types in text reading and did not encompass visual confusions, semantic substitutions or non-specific guesses. McGuiness (1997) does emphasise the importance of classroom teachers taking the time to analyse reading errors, particularly for children experiencing difficulty in order to assist them appropriately. She states:

> …it is of considerable importance to reading instructors to know how a child is attempting to decode words from print. A child’s reading strategy is essentially ‘invisible’ to a classroom or remedial teacher without appropriate testing. This type of error analysis can be carried out by anyone who can decode oral errors phonetically. This is especially important in view of the finding that decoding strategies employed in first grade predict a significant proportion of the variance in third grade reading… (McGuiness, 1997, p. 136).

Stothard and Hulme (1995) compared the reading abilities of students with poor decoding abilities (decoding at least 6 months poorer than comprehension) and readers with good decoding but poor comprehension (comprehension at least 6 months poorer than decoding). They found that the readers with good decoding and poor comprehension had normal phonological awareness skills, but the poor decoders had poor phonological abilities. They inferred that the phonological skills influenced decoding ability. Poor decoders have also been noted to have particular difficulty preserving the order of phonetic segments (Brady et al., 1983). Hence, any system of error analysis must tease out phonological decoding errors.

Swan and Goswami (1997b) investigated the picture and word naming abilities of readers with dyslexia, LSR and compared these to reading age matched controls and chronological age matched controls. Both the readers with dyslexia and the LSR had difficulty with word and picture naming. In addition, readers with dyslexia made significantly more errors on more polysyllabic and low frequency words than the LSR. This was interpreted as showing a phonological basis for the errors in readers with dyslexia. Further evidence was found to support that readers with dyslexia have greater difficulty retrieving words from the long-term lexicon whereas LSR have a deficient vocabulary from which to draw upon. Overall, the errors of readers with dyslexia were phonologically closer to the target than the errors made by the LSR. The errors made by readers with dyslexia also retained the same initial sound and same syllable length as the target compared to the errors made by LSR.

It is important to be cognizant of the fact some reading errors are actually strategies and that some strategies are more useful than others. Therefore the use of the word 'error' usually refers to an incorrect production (or no production) of the target word. The actual sequence of strategy development is not fully understood. In addition, there is no evidence of a necessary sequence of strategy development and it is likely to vary with each individual. Nevertheless, McGuiness (1997) emphasises the importance of detecting strategies that have become 'maladaptive' habits and therefore by implication, error analysis needs to become an essential part of good teaching practice.

2.7 Sentence Reading Processes

Rapid word reading skill forms only a part of successful text reading comprehension, which is the ultimate purpose of reading (Oakhill et al., 2003). Recognition does not equal understanding. A thorough assessment of reading needs to evaluate grapheme-phoneme conversion, nonword reading, single word reading *and* text reading (Goulandris, 1996). Only in text reading can errors of meaning, whole word additions or whole word deletions occur. Text reading assessment allows evaluation of reading fluency, reading accuracy and reading comprehension. Word prediction also plays a role in reading accuracy, especially in proficient readers who benefit from rapid word recognition (Stanovich, 1986). However, it is estimated that only 10-20% of words in text can be accurately predicted from context alone. For the remainder of the words the reader needs to self-monitor any influence of prediction against the available visual and phonological information, ideally prior to production when reading aloud (Gough

& Tunmer, 1986; Lyon, 1999). For example any inclination to produce the word ‘beetroot’ on the end of the sentence ‘She was as red as a postbox’ should be modified in light of the conflicting available information. Therefore, efficient visual recognition and phonological decoding skills are essential components of fluent reading in text reading assessments.

Some researchers suggest that difficulties with both word reading and sentence reading stem from a common deficit in phonological processing (Shankweiler, 1989). Certainly this view has merit when considering a word-by-word text reading approach where the reader is focussed solely upon word accuracy through recognition and identification. However, text is conveying a meaningful message to the reader who has the task of comprehending that message. When a sentence is not understood this can occur for one of two reasons. Firstly, the vocabulary and associated semantics within the sentence may not be understood (Kay et al., 1996). Secondly, PWM limitations may impair the syntactic processing required for sentence comprehension (Kay et al., 1996).

2.7.1 Syntactic System

The effects of syntactic processing upon reading comprehension are investigated under the structural deficit hypothesis i.e. that reading difficulties occur due to language difficulties (Crain, 1989; Shankweiler, 1989).

Shankweiler (1989) compared the structural deficit hypothesis to the phonological deficit hypothesis in relation to reading comprehension and found that complex structures such as relative clauses were problematic for poor comprehenders due to working memory difficulties. PWM difficulties affect the recall of sequence in particular, rather than deficits in syntactical understanding. This finding was inferred from the results of an earlier study by Mann, Shankweiler and Smith (1984) which showed that while the performance of poor third grade readers (n = 17) was poorer on all four types of relative clauses presented compared to the good readers (n = 18), the pattern of errors reflected the level of difficulty of the sentence in the same way as the performance of the good readers. The poor readers were still able to correctly comprehend all types of sentences containing relative clauses indicating that they did not lack an understanding of the syntactic structure per se, but a difficulty in processing larger amounts of information in non-sequential order in some of the sentences i.e. working memory. For instance, they have difficulty relating elements of a sentence that are separated by greater distance. This was confirmed in the second stage of the study that demonstrated that the poor readers had greater difficulty than the good readers in recalling the sentences verbatim, once again implicating PWM difficulty rather than language difficulty. Mann et al. (1984) concluded that comprehension difficulties will ensue if the language processing task places high demands on PWM. Their concluding comments were:

> The successful language learner must somehow assess large portions of the phonetic structure of the utterance at hand, and rely on word order and certain phonological features to establish the correct syntactic structure and therefore, the correct meaning of the utterance. It is for this purpose, we suspect, that phonetic representation in working memory exists in the first place. Thus a deficient capacity to form phonetic

> representations may limit the development of syntactic competence. ……we would note that the language tasks that best distinguish good and poor readers are most often precisely those that place special demands on phonetic representation. (p.642)

The above findings were replicated in a single case study by Baddeley and Wilson (1988) who found that TB, a 55 year old male mathematician with reduced short-term memory following brain injury was able to comprehend single words and sentences up to three words in length but had progressively greater difficulty as sentence length increased. Analysis of the longer sentences suggests that difficulty occurs when one part of the sentence is distant from but linked to the meaning of another part of the sentence e.g. “The girl that held the cat is only three years old” where the girl and her age are separated by six intervening words. Again, there was no evidence of syntactic difficulties in his expressive language or in the understanding of syntax on grammatical testing. Nevertheless, Baddeley and Wilson acknowledge that it is difficult to deconfound syntax and sentence length altogether. They concluded that the evidence suggests that loss of comprehension of syntactically more complex sentences is due to load on the phonological loop rather than a linguistic deficit.

Crain’s (1989) research supports these findings and he concluded that: “the apparent failure of poor readers on a linguistic structure can result from the influence of nonsyntactic factors that mask their knowledge of syntax” (p.161). A common conclusion is that efficient phonological working memory is necessary for sentence comprehension so that semantic and syntactic analysis can occur.

2.7.2 Language and Literacy

It is well established that a high number of children with language impairment go on to have reading difficulty (Share & Leikin, 2004), with reported figures as high as 70% (Bishop & Adams, 1990; Snowling, Bishop & Stothard, 2000). Strong relationships between oral language skills and literacy ability have been consistently reported in the literature. Bishop and Adams (1990) investigated 69 children who had demonstrated early language impairment. When the language impairment had resolved by 5 1/2 years of age, the children attained normal levels of literacy competence, but those with ongoing language impairments also had impairments of literacy development, most notably with reading comprehension. A longitudinal investigation by Catts, Fey, Tomblin and Zhang (2002) also demonstrated that children with language impairment (n = 328) in pre-school were at high risk for poor reading outcomes in both second and fourth grade. About 50% of these children would qualify as having a reading disability corresponding to six times the number of children without language impairment (n = 276). Retrospectively, Catts et al. (2002) found that 73% of second grade poor readers (n = 570) had a history of spoken language difficulties in the pre-school years. There is also evidence to suggest primary age literacy difficulties extend into adolescence. Stothard et al. (1998) found that 52% of adolescents with resolved speech and language impairments continued to have literacy difficulties and 93% of adolescents with persistent speech and language impairments had ongoing literacy difficulties. The above studies provide solid evidence that language competency is essential for literacy competency.

The prevalence of concomitant language and literacy difficulties is high. Heath and Hogben (2004) found that at least 50% of students with reading disabilities on their clinical database scored greater than one standard deviation below the mean on oral language testing. Age range and exact numbers were not stated. It is also reported that 55% of dyslexic students have impaired language and 51% of language impaired students have dyslexia (McArthur & Bishop, 2001). From a local perspective it is known that 7.3% of South Australian students receive special education funding under the Students with Disabilities policy criteria. Of those students, 73% are known to have a language or communication impairment (2003).

Scarborough (1990) found that children (n = 20) who were later diagnosed with dyslexia showed reduced grammatical complexity and shorter sentence length at 2 ½ years of age. At 3 years of age and 3years 6 months these same children also showed reduced receptive vocabulary abilities and reduced object-naming abilities. Scarborough's results were consistent with the findings of Gallagher et al. (2000) who found that children who were experiencing delays in their literacy development at 6 years of age also scored more poorly on vocabulary tests at 3 years 9 months. Scarborough (2005) summarised that what distinguished children who were later diagnosed with dyslexia from normally achieving readers was syntactic and vocabulary abilities at 3 ½ to 4 years and vocabulary and phonological awareness at 5 years of age. The findings highlight the need for caution about correlations, when the interpretation may be age dependent.

Snowling, Bishop and Stothard (2000) found that among 71 adolescents who had a history of pre-school language impairment, 48% met the criteria for reading disability at the age of 15 (by virtue of reading abilities being greater than 2 years behind chronological age), even though at age 8 years there was no significant difference between their reading abilities and the reading abilities of the control participants matched for age and IQ. The inference is that weak language skills have impeded reading development, reducing reading comprehension despite good phonological skills. Snowling (2000a) emphasised the compounding of difficulties for the student with reading disability when there is concomitant language impairment, hindering compensation via the semantic route. The apparent normal reading observed in an earlier study by Bishop and Adams (1990) once language impairments had resolved may have been deceiving and short-term, with the weaknesses resurfacing as the reading task becomes more demanding. In summary, the literature reviewed above highlights the importance of sustaining vocabulary expansion despite low reading experience or language impairment, to ensure good reading outcomes.

Snowling (1998) explains that the evidence from longitudinal studies in the early years would support that words stored within the long-term lexicon are more readily acquired as early sight words (Scarborough, 1990; Gallagher et al., 2000). For instance, Gallagher concluded that existing phonological representations for both sounds and words serve to establish the mappings between phonology and orthography during early literacy teaching (Gallagher et al., 2000). Snowling (2000) states that: “learning to read is supported by vocabulary knowledge to a larger extent than is sometimes acknowledged” (94).

Vellutino et al. (1995) present a contrasting view. They found that the semantic capabilities, including receptive vocabulary, of readers reading at two years or more below age level (n = 15) was not significantly impaired compared to a control group (n = 15) at second grade, but was significant at sixth grade (n = 30). The implication, was therefore, that reduced reading experience was beginning to have an impact on semantic development, in keeping with the ‘Matthew effect’ whereby good readers get better and LSR fall further behind (Stanovich, 1986). However, while the participants in Vellutino’s study were reading at two or more years below age level, they were not grouped according to reading subtypes of dyslexia or LSR, but as ‘poor’ readers and there were 30 subjects in each age group, divided into 15 ‘poor’ readers and 15 normal readers, resulting in a relatively small sample size.

While some vocabulary is directly taught, the majority of vocabulary is acquired through inductive reasoning from either spoken or written language i.e. inferred from context (Stanovich, 1986). Consequently, Stanovich strongly argues that the relationship between vocabulary and reading is reciprocal: a strong vocabulary is an advantage to reading success, but reading experience nourishes a stronger vocabulary.

The neurological activity of individuals with reading disabilities during semantic tasks has been investigated. Booth, Bebko, Burman and Bitan (2007) compared neuroimaging information in an *f*MRI study during semantic processing tasks between a reading disordered group (n = 15) who obtained a standard score below 95 on four reading measures and control group (n = 15) aged 9 to 15 years. The groups were age matched to within 4 months. The aim was to determine whether three regions were consistently related to a semantic processing. The three regions were the left inferior frontal gyrus, left inferior parietal lobe and left middle temporal gyrus: all three areas having been previously implicated in semantic processing (Booth et al., 2007). Forty-eight word pairs were auditorily presented: 24 pairs were semantically unrelated and the remainder were either high association pairs (e.g. king-queen) or low association pairs (e.g. net-ship). The semantic judgement task in the Booth study required the participant to decide whether two words presented auditorily were related. The responses of the reading disordered group were significantly slower and less accurate than the control group. The findings held true for visual presentation of printed word pairs. Of great interest, Booth et al. discovered that there was greater activation in the left middle temporal gyrus, left inferior parietal lobe and left inferior frontal gyrus in normal readers (n = 15) when the links between two spoken words were weaker, but this effect was absent in the poor reader group (n = 15). For items with low association, activation was significantly weaker in both the left inferior parietal lobe and left middle temporal gyrus but was significantly higher in the left inferior frontal gyrus, a region thought to be involved in retrieval of semantic information. To use the flashlight analogy (Kintsch et al., 1999) the results suggest the flashlight is not lighting up in some of the darkened areas of LTM for the reading disabled group for weakly related words which may reflect inefficient processing or alternatively might indicate that rich semantic links were absent in the poor reader group.

Summarising the Booth et al. study, the strength of activation in left inferior parietal gyrus and the left middle temporal gyrus was enhanced for the control group when the paired items had a low association. These two areas are thought to be responsible for semantic categorisation (in preparation for determination of relationships) and for drawing upon semantic information from related sources respectively. This effect was not observed in the reading disabled group. The highly associated pairs also led to greater activation in the left inferior parietal region in the control group, but again this effect was not observed in the reading disabled group. It was postulated that in the absence of strong semantic representations in the left middle temporal gyrus, possibly the high activation of retrieval mechanisms in the left inferior frontal gyrus attempt to compensate. The conclusions of this study state the reading disordered group “have deficits in the quality of their semantic representations, the integration of semantic features and the access and manipulation of these processes” (Booth et al., 2007, p. 781). The underactivity in the temporal lobe, the region responsible for processing auditory input and accessing semantic representations (and related semantic information) strongly suggests auditory processing difficulties, semantic representation difficulties and/or semantic retrieval difficulties in the reading disabled group.

The relationship between vocabulary and reading is not straightforward however. McGuiness (2005) points out that across studies, correlations between standardised measures of vocabulary and standardised measures of reading have ranged from zero to 0.70. Further, McGuiness (2005) reports from her own studies that only a small percentage of children have vocabulary performance ability that is impaired to the degree that it would have an impact on reading development. A more recent study appears to conflict with the contribution that semantic knowledge makes to reading ability. An investigation of this relationship found that at the word level, phonological representations of vocabulary played a greater role in reading accuracy than semantic knowledge in 7 year-olds (n = 27) with average reading ability (Nation & Cocksey, 2009). Firstly, existence of a phonological representation was evaluated by asking the participant whether 128 randomly presented spoken words and nonwords were real or not (lexical decision). The same written words were then evaluated for reading accuracy.

Thirdly, semantic representation was established by requesting a definition of the spoken words. It is acknowledged by the authors that the phonological representation task may tap semantic knowledge to varying extents when asking whether a word is real or not. It was found that the existence of a phonological representation was more important for reading success than existing semantic knowledge. An existing phonological representation was even more important for successful reading of irregular words than regular words. It is not surprising that unfamiliar irregular words would be more difficult to decode in the absence of an existing phonological representation.

The above results may also be different for text level reading accuracy where semantic knowledge plays a more important role in reading accuracy with subsequent effects on comprehension. At the isolated word level, the task is primarily one of decoding in the absence of context. Using the earlier example, when decoding the orthographically unfamiliar word ‘wizard’ a child might use the phonological (grapho-phonemic) route to decode ‘w-i-z’ but then switch to support from existing phonological and/or semantic representations to arrive at ‘wizard’ if the word is stored in the long-term lexicon. This previously unfamiliar written word is more likely to be recognised on the next encounter because its phonological representation and meaning was already stored. Whole words that are not stored in the long-term lexicon cannot be predicted while reading text, thus affecting fluency. This was tested by Pring and Snowling (1986) by asking children in two reading-age groups without reading disability, one with a mean reading age of 8 years 3 months (n = 20) and the second with a mean reading age of 10 years 3 months (n = 20), to decode the second word in a word pair containing either an expected or unexpected second word. The older group was faster at naming the second word in both cases, but it was demonstrated that the children in both reading-age groups successfully performed better on expected rather than unexpected words. In a further experiment by Pring and Snowling (1986), real words were paired to a novel spelling with a semantic cue (e.g. doctor- nurce) and compared to an unrelated pair (e.g. doctor-furst). The semantic cue facilitated the younger readers ($n = 14$) significantly ($t = 2.764, p<0.05$), but not the older readers ($n = 14$) ($t = 0.632$, ns). This is an important finding, as it suggests that normally developing younger children can effectively ‘teach’ themselves to logically predict unfamiliar words if they actively use semantic cues.

It is argued that language skills alone are not sufficient for good comprehension which also requires the ability to reason about the text e.g. reflecting upon related prior knowledge, the intended meaning of the text, the purpose of the text, new information learned and analysis of the value of the text (Lyon, 1998). Perhaps language skills and reasoning skills are linked. One theory is that the same processes are required for vocabulary acquisition and language comprehension. For instance, it is known that individuals with strong comprehension skills are more efficient at extraction of meaning of words in context, as outlined by Brackenbury and Pye (2005) and Sternberg and Powell (1983). Normally developing readers (mean age: 9;2) have also been found to be better at synonym judgement tasks than poor comprehenders (mean age: 9;3), supporting good meaning extraction abilities in good readers (Nation & Snowling, 1998b). The ability to extract meanings would also assist vocabulary acquisition when new words are encountered in verbal contexts. This would hold true for the population without AP deficits. However, in the presence of AP deficits, cognitive skills may be intact but cannot be efficiently applied to the auditory information, due to low integrity of the signal or loss of information.

2.7.3 Reading Comprehension

It is known that speech and print input must have separate access to the semantic system, as indicated on the PALPA model. Conditions such as word deafness where spoken input is not understood yet printed input can access meaning and the converse condition of alexia whereby speech input is understood but written input is not provides solid evidence for the different access routes (Coltheart et al., 2001). *f*MRI studies have shown that during reading comprehension tasks activation was lateralised to the left hemisphere and there was little activation in the right temporal region, unlike listening comprehension (Michael et al., 2001). Therefore, while there may be a single semantic repository, the access routes are clearly not the same for listening comprehension and reading comprehension.

Speech processing in listening comprehension tasks is processed via the *phonological input buffer* and the *phonological input lexicon*, whereas print processing for reading comprehension tasks is processed via the *orthographic input lexicon,* according to the PALPA model. According to Luo (1996), the printed word activates *both* a phonological code and an orthographic code. Both codes activate semantic access, but for evolutionary reasons the phonological code is assumed to be faster i.e. speech existed before print. When more than one semantic representation is triggered, because of imprecise phonological or semantic representations, the orthographic code may assist to self-monitor selective retrieval i.e. resolve the confusion (Luo, 1996).

Reading comprehension has been defined as: “the process by which, given lexical information, sentences and discourse are interpreted” (Gough & Tunmer, 1986, p. 7). Both listening and reading comprehension require processing and storage of processed material, making room for incoming information (Gathercole & Baddeley, 1993). The only current method of evaluating reading comprehension entails either asking questions about the content with an expectation of verbal or written responses in the form of prose or multiple choice selections. These methods provide snapshots of the reader’s understanding, but cannot truly reflect the individual’s full interpretation of text.

The components of successful reading comprehension overlap substantially with the components of listening comprehension. Recall that literacy skills have been overlaid on the existing neurological system for comprehension of speech. Comprehension of the written message, however, relies on the same linguistic system that processes listening comprehension, designed to receive information at normal speaking rate. In normally developing readers aged 7 years 7 months to 8 years 11 months, de Jong et al. (2009) found that reading comprehension was significantly better after reading aloud than after silent reading. It is presumed that the phonological input more successfully and consistently triggers semantic activation. Greater success occurs due to the ‘natural’ route of linguistic processing being utilised. When the process of accessing print slows the rate of information flow then comprehension is likely to suffer. Of course, if the individual is illiterate, reading comprehension is not possible.

As there is no auditory input in silent reading, speech perception is replaced by visual perception (of letters and words) while the other process components below, each having been reviewed already, remain:

a) attention;
b) phonological input buffer or PWM;
c) long-term memory:
    i. orthographic input lexicon/word identification (written vocabulary store);
    ii. semantic system (matching vocabulary to meaning);
d) knowledge of syntactic structure;
e) cognitive integration of incoming information with past literary experiences and general knowledge about the world, mediated by the central executive and;
f) *when* reading aloud, the phonological output lexicon and phonological output buffer are activated.

Vocabulary is one key aspect of language skill associated with literacy outcomes. Lundberg (2002) estimated that when 20% or more of the words in a text are not understood, then comprehension will be compromised. Oakhill et al. (2003) found strong correlations between the British Picture Vocabulary Test (Dunn, Whetton & Pintillie, 1982) and the Reading Comprehension measure on the Neale Analysis of Reading Ability–Revised (Neale, 1989) in a longitudinal study of children tested at 7 to 8 years of age and again at 8 to 9 years of age. It can be said that there is general consensus that a low vocabulary contributes to low oral language comprehension and a strong vocabulary is therefore a contributing factor towards competent reading comprehension (Wixson, 1986).

Vocabulary alone, while critically important is not sufficient for listening or reading comprehension. In a study where vocabulary knowledge of upcoming content was ensured prior to a reading comprehension task, comprehension difficulty was not eliminated for a group of 7-8 year olds (Stothard & Hulme, 1992). Text reading is taxing on the central executive and PWM.

A large-scale study by Bishop et al. (2009) investigated typically developing readers (TD; n = 176), dyslexic readers (DX; n = 73), readers with language impairment (LI; n = 35) and readers with both dyslexia and LI (LI+DX; n = 54). At 9 years of age, they found that readers with LI exhibited significantly poorer reading comprehension and poorer reading rate than the TD group on pairwise comparisons. Single word reading was significantly better in the LI group than either the DX group or the LI+DX group but poorer than the TD group. Naming was unimpaired in the LI group. Interestingly, the LI group showed no difference in phonological awareness or PWM ability at 4 years compared to the DX group. The conclusions were that LI significantly affected reading comprehension and text reading fluency, but single word decoding less so. The salient features of the LI group were a weak vocabulary, poor sentence recall and poor reading comprehension. Reading ability fell within the average range at the lower end compared to the TD group whose reading abilities approximated the mean on all measures.

There is a further group of students whose reading difficulties do not emerge until later in their schooling. These students are often referred to poor comprehenders. Poor comprehenders are typically readers with good phonological awareness and decoding abilities accompanied by poor reading comprehension. About 10-15% of children aged 7 to 11 years could be classified as poor comprehenders, according to studies performed in the UK (Yuill & Oakhill, 1991). Research investigating poor comprehenders has consistently found semantic deficits in this group. Poor comprehenders have been shown to have deficits in judging whether words are real or not, providing definitions of words and in semantic fluency tasks, such as rapidly providing words associated with a category label e.g. fruit. In picture naming tasks, poor comprehenders make semantic errors whereas poor decoders make phonological errors (Nation, Snowling & Clarke, 2007). However, many of these individuals would not be considered to have a language impairment, often scoring in the low average range on language tasks (Nation, 2005). For this reason, poor comprehenders often go undetected in the early years until reading comprehension deficits compound in later years (Catts et al., 2005).

Nation and Snowling (1998b) investigated poor comprehenders (n = 16; mean age: 9;4 years) compared to controls (n = 16; mean age: 9;2 years) matched for decoding ability, age and nonverbal ability. Their aim was to determine whether poor comprehenders experience differences reading words requiring different levels of phonological or semantic support. They found that poor comprehenders made significantly more reading errors, had significantly greater difficulty reading low frequency words, especially low frequency irregular words. Both word types require greater semantic support compared to high frequency or regular words. As an important further finding when the two groups were separated on vocabulary ability based on scores on the *Test of Word Knowledge* (high word knowledge with a score greater than 100 vs. low word knowledge with a score less than 100), the results were remarkably similar. The group with low word knowledge also had significantly greater difficulty reading both low frequency and irregular words.

In the above experiment it was also determined that poor comprehenders performed significantly poorer on a synonym judgement task being significantly slower to respond, particularly on the low-imageability items. In another study investigating contextual facilitation, Nation and Snowling (1998a) found that while poor readers, both dyslexic and poor comprehenders, attempt to use contextual facilitation for word recognition more than good readers they do not benefit from context as well as good readers. The readers were asked to firstly read a sentence that provides context and then an isolated word related to that context. Further analysis of the three groups of participants showed that the dyslexic readers used context to assist word recognition more than good readers and both groups used contextual facilitation more than the poor comprehenders, who generally failed to benefit from context (Nation & Snowling, 1998a). This is not surprising, given that dyslexic readers are slow decoders and need to take advantage of contextual information whereas word identification is more automatic for good readers. It is likely that highly developed contextual facilitation is the reason that many dyslexic readers achieve good levels of reading competency in later schooling, particularly when language skills are strong. However, the question remains whether it is language deficits or PWM deficits (with or without suboptimal decoding) that result in the difficulties observed in poor comprehenders within the LSR group.

The capacity theory essentially addresses the trade-off between capacity (amount of energy available) and load (amount of energy required) (Just &

Carpenter, 1992). When the system is overloaded, some of the information may be lost and the individual encounters difficulty with the task. This is called *capacity constrained comprehension*. If the capacity is being used for decoding while reading, there will be less capacity available for comprehension. However, the system needs to have adequate capacity *and* efficiency. Just and Carpenter (1992) acknowledge that individual differences will occur in strategies employed during comprehension, having an impact on efficiency. For instance, some individuals will have a tendency towards better recall of recent information (recency effect), earliest information (primacy effect), selection of the most relevant information, ability to predict upcoming information or conversion of information in a summarised form. The efficiency of these strategies, especially when the capacity of working memory is strained, will affect the degree of comprehension. In support of this, Just and Carpenter (1992) demonstrated that as the comprehension demands of a sentence increase the ability to recall sentences verbatim reduces.

In the case of TB, the 55 year old male mathematician with impaired phonological loop function, reading comprehension for sentences was impaired but to a lesser extent than listening comprehension for sentences. This is to be expected given the nature of the written word allowing a permanent point of reference, but also suggested that greater PWM capacity is needed for listening comprehension than reading comprehension. TB’s silent reading time was slower than normal reading rate and his responses to questions were delayed, by up to 76.5 seconds. When asked to read aloud Baddeley and Wilson (1988) described TB’s approach to the sentence reading task “as a problem-solving exercise in which he would successively read individual components of the sentence, trying to fit them together as if he were solving a verbal jigsaw puzzle" (p.492). In a third condition when asked to read aloud at normal reading rate and answer comprehension questions immediately afterwards, TB's performance was no better than by chance. TB is known to have a deficit of the phonological loop and this case study provides good evidence of the role of the phonological loop in reading.

The incoming information to the PWM activates retrieval of related information in LTM in order for comprehension to occur. If PWM is limited, less information is retrieved from LTM and comprehension is compromised (Kintsch et al., 1999). Gathercole and Baddeley (1993) proposed that it is logical that individuals with low PWM also have reduced capacity for holding representations of meaning while reading, affording less use of context and difficulty dealing with incoming new material efficiently. In addition, the information retrieved must be of sufficient quality for comprehension to occur.

The reading span task is frequently used in reading comprehension research. In this task, the participant is asked to read a series of unrelated sentences and then recall the last word of each of the sentences. The task was devised by Daneman and Carpenter (1980) who state that the task is a reflection of processing and working memory. Individuals with poor reading span results are reported to do poorly on reading comprehension tasks with a mean correlation of .66 (range: 0.42 to 0.90). Criticisms of the reading span task argue that it is not a test of working memory, but is simply a test of reading comprehension itself. A second criticism relates to the observation that individuals can approach the task differently e.g. paying particular attention to remembering the final words without comprehending the sentences (Goff, 2004). To address these concerns, variations to the task have been developed with a focus on ensuring sentence reading by asking whether the information was true or false or whether the sentence made sense after each sentence.

In one experiment of good comprehenders compared to poor comprehenders aged 9 to 10 years, Nation, Adams, Bowyer-Crane and Snowling (1999) found that the poor comprehenders had performed significantly poorer on a reading span task. The participants were required to decide whether short sentences were true or not and also retain the last word of each sentence presented. Sets of two, three, four and five word sentences were presented. At the completion of the sentence set, the participant was required to list the last word from each sentence in order. The poor comprehenders had greatest difficulty as complexity of the task increased. Importantly, the poor comprehenders did not perform poorly on a visuospatial working memory task indicating that the working memory deficit was specific to verbal tasks. It was concluded that the poor comprehenders have difficulty processing and storing verbal material, but do not have a generalised working memory deficit. The researchers take the view that because the deficits occur only in the verbal domain, the difficulties represent limitation of the language system and not working memory.

Oakhill et al. (2003) found a significant correlation between reading comprehension on the Neale Analysis of Reading Ability-Revised (Neale, 1989) and PWM tasks (word and sentence memory) at both 7 to 8 years of age and 8 to 9 years of age. Interestingly, a correlation between short-term memory and reading comprehension was not found in the younger age group but a moderate correlation was found in the older age group, based on a digit span task (Oakhill et al., 2003). It is likely that better PWM is a contributing factor to the findings of

Cataldo and Oakhill (2000) that good comprehenders were significantly better at remembering the order of information in text and therefore seemed better able to search and scan for information needed for answering comprehension questions. Good comprehenders who had strong reading span results were also better at understanding the correct referents for pronouns used at a distance from the original referent across sentences.

Nation et al. (1999) evaluated spoken word recall in another experiment of good comprehenders compared to poor comprehenders aged 9 to 10 years. The ability of poor comprehenders to recall words was no more greatly affected by the length of the words than good comprehenders and the poor comprehenders were equally able to determine whether words were real or not. This suggests that short-term memory skills are intact. However they had significantly greater difficulty recalling words that were less concrete and more abstract, suggestive of weakness in semantic representations. When words are heard, the phonological and semantic representations are activated, each assisting the retention of the other. Nation et al. concluded that poor comprehenders (with no decoding difficulty) in their study group had intact phonological representations, but weak semantic representations. The poor comprehenders did not have difficulty with a spatial memory task and therefore the difficulties could not be attributed to a general working memory difficulty, but one specifically in the verbal domain. Oakhill et al. (2003) support this view, suggesting that the ‘richness’ of semantic representations may be critical for reading comprehension. They state that: “if word meanings are poorly represented in semantic memory, less information will be accessed and perhaps fewer relations between concepts will be made than if a rich semantic representation for word meaning exists” (p.463).

In the simple view of reading, reading (R) is calculated to be the product of decoding (D) and comprehension (C) i.e. R = D x C (Gough & Tunmer, 1986; Nation, 2005). When the value of either D or C is zero then R will be zero. A correlation of word decoding ability and comprehension ability of 0.41 was found in 8 to 9 year olds (Oakhill et al., 2003), therefore word reading alone is not sufficient for comprehension. Oakhill et al. (2003) found evidence that word reading and text comprehension rely upon different underlying processes. Namely, significant variance in word reading could be accounted for by a phoneme deletion task (which requires phoneme segmentation and PWM) whereas text significant variance in text comprehension could be accounted for by text integration (including inference), metacognitive monitoring (finding information in the text that does not make sense) and PWM (Oakhill et al., 2003). Additionally PWM ability correlated significantly with metacognitive monitoring at 7 to 8 years of age and both inference and metacognitive monitoring at 8 to 9 years of age in their large-scale longitudinal study (n = 102). The only phonological task that was significantly correlated with reading comprehension at both 7 to 8 years and 8 to 9 years of age was an odd-one-out task (selecting the word from a list of four words that started or ended with a different sound). The researchers also attributed this correlation to the demands on PWM.

The findings of Stothard and Hulme (1995) appear to support the above findings. In their study, good and poor comprehenders did not significantly differ in phonological awareness ability, on a range of tasks. It would seem therefore, that phonological working memory is a vital component of successful reading comprehension, but phonological awareness ability is not.

It is important to point out that poor comprehenders are a very specific group of poor readers: a subgroup of LSR, which is also comprised of poor decoders and mixed deficit readers. One criterion for inclusion in the poor comprehender group is good word decoding ability. By definition, therefore, the relationship between *poor* word reading ability and poor comprehension is dissociated for the purposes of the research. The research on poor comprehenders is reviewed here because the findings must be taken into consideration for any individual with low comprehension abilities. That is, deficits in metacognitive monitoring and/or text integration may also be present whenever there is a finding of low reading comprehension ability.

As previously mentioned, poor readers rely more heavily on context for word prediction than good readers because they are less able to achieve rapid rates of word identification (Stanovich, 1986). However, context can only assist the poor reader if they are able to understand the context. Consequently when vocabulary and semantic knowledge are weak, then the potential for context to assist comprehension is diminished. Decoding an unfamiliar word can only activate semantic representations of word meaning already established in long-term memory. The observation that good readers can predict words in text, does not mean that prediction is necessary for proficient reading. Instead, the aim of the competent reader is to achieve 'context-free' decoding i.e. freeing capacity *after* word identification for comprehension processing (Stanovich, 1986). Nevertheless, even context-free word identification cannot ensure comprehension if semantic knowledge is poor.

Logically, listening comprehension and reading comprehension rely on similar processes (Nation, 2005). In typical adults, a correlation of 0.9 has been reported between listening comprehension and reading comprehension (Bell & Perfetti, 1994). While it is wholly logical to state that if a child cannot understand a spoken sentence then it cannot be expected that they will understood the same sentence when it is read silently or aloud. But is this true of individuals with APD? What if it is only the processing of *spoken* information that causes difficulty? Logically, it may then be possible for vocabulary and concepts to be understood from text when no processing of speech input is required.

2.7.4 Sentence Reading Errors

A range of approaches to analysing sentence and text reading errors have been proposed over the past fifty years. A sample of these approaches will be reviewed here.

Goodman's Reading Miscue Inventory (RMI) was developed in the 1960s. The RMI is based on Goodman's belief that reading is a top-down process in which context aids word recognition. The reader uses syntactic, semantic and grapho-phonemic cues to predict the word. Any departure from the target word is labelled a 'miscue' rather than an error (Weaver, 1994). For instance if a child reads 'The little truck had it ' instead of 'The little monkey had it' the child has used the syntactic cue but made a semantic miscue. This gives credit to the reader for the cues that they are attending to but in reality there are many errors that do not fit into the miscue categories. Goodman's RMI sits comfortably with educators who promote that reading development should be foremostly focussed on construction of meaning rather than fluent word recognition with meaning as a secondary aim. Goulandris (1996) argues that word recognition occurs so rapidly in competent readers that there isn't time for contemplating context for each word. Therefore, Goodman's MRI is inadequate to encompass all the possible errors of recognition observed for single word reading plus account for commonly observed text reading errors such as word additions, word deletions, losing the place or re-reading (recasting) a phrase to assist recognition of the upcoming word e.g. "a man with bread… a man with a beard". Advocates of Goodman's context-driven approach to reading do not support testing of nonwords or words in isolation from text and contest that this "may often underestimate the ability of seemingly less proficient readers to construct meaning from connected, coherent and authentic text" (Weaver, 1994, p. 26). However, the general consensus now promotes thorough reading assessment of nonwords, isolated words and text reading (Coltheart & Leahy, 1996; Goulandris, 1996). Nonword reading provides invaluable information about phonological decoding, word reading provides invaluable information about word recognition while text reading adds information about ability to use syntactic and semantic context as well as additional observations regarding motivation, attention and visual processing.

The Observation Study by Clay was first published in 1993 and forms part of the Reading Recovery Programme used widely in Australian and New Zealand schools until recently. The educator obtains a 'running record' or transcription of the child's reading. Errors are analysed as to whether they were predominantly influenced by meaning, structure (syntax) or visual information (Clay, 2002). These are coded as M, S or V respectively. Self-corrections are also recorded. This analysis blends the miscue analysis and more traditional error analyses by allowing the educator to see what the reader is paying attention to and the cues they are not giving sufficient attention to. This information is useful in guiding intervention. A similar error analysis is used in some reading tests such as the Gray Oral Reading Tests (GORT) (Wiederholt & Bryant, 2001).

Coltheart et al. (1994) proposed that as the reader matures important decoding developments occur. As 1:1 letter-sound correspondences are recoded to incorporate orthographic chunks (e.g. -ough, -air etc.) progressively greater segments of the word are phonologically converted until an acceptable semantic ‘fit’ is achieved. The chunks become bigger, and progressively more words are recognised in their entirety. Luo (1996) suggests that when phonological mediation activates more than one lexical entry, including entries that are inappropriate to the context, the incorrect entry results in interference to semantic cohesion of the sentence. The conflict disturbs attention, capacity and working memory processes as all these resources are directed to resolve the conflict. The reader then seeks decisive orthographic information to resolve the confusion, but may or may not produce the corrected word aloud. If the word read aloud is incorrect it will be recorded as an error, usually of substitution. Of course, it is difficult to be certain whether the error has been corrected silently, but this may explain why some seemingly inaccurate readers demonstrate higher reading comprehension than expected.

New et al. (2006) studied the effect of word length on word identification in text reading. New et al. (2006) found that short words of 3 to 5 letters are most commonly skipped in text reading and this is thought to be due to saccadic eye movements. The extent of saccadic movements correspond with about three to four letters to the left and fourteen to fifteen letters to the right, though only seven to eight letters to the right will be recognised (Shillcock, 2007). As the perceptual span extends to the right from the target word, the upcoming word *after* the short word may then capture visual attention e.g. in the phrase ‘caught a whiting’, while reading ‘caught’ the word ‘whiting’ may capture visual attention and also semantic attention because it is a higher information carrying word. This would explain frequent omission of ‘a’, ‘an’ and ‘the’ in many poor readers.

Clearly, many factors combine for proficient reading but conversely, must also be drawn out in a comprehensive analysis of reading errors. Munro (1995) makes the point that teachers are frequently experiencing the reading errors that students are making, but not always using this knowledge to determine the source of the reading breakdown. Comprehensive error analysis would guide appropriate reading intervention for these students as supported by Goulandris (1996) who stated:

> A pupil whose word recognition is excellent but comprehension limited will require very different remediation from a child who makes numerous reading errors but can nevertheless answer searching questions about the text, if the unfamiliar words are supplied. (p.93)

Goulandris (1996) attempted to incorporate some of the complexities of text reading error analysis in a behavioural observation guide. Errors of word recognition, decoding and prediction are accounted for in Goulandris’ system. Comments on whether syntactic or semantic predictions (substitutions) are meaningful are recommended. Notes of behaviours in relation to reading rate, self-corrections, expression and use of cues were also recommended. Observational notes are also encouraged in tests of reading such as the Neale

Analysis of Reading Ability (Neale, 1989, 1999). The formal error count on the Neale Analysis of Reading Ability tallies mispronunciations, substitutions, refusals, additions, omissions and reversals. Each error type is then calculated as a percentage of total errors. However, neither system affords a tally of all error types necessary to analyse the underlying source of the deficits. For example, substitutions of a single sound e.g. ‘cape’ for ‘tape’, a syllable (or morpheme) e.g. ‘followed’ for ‘following’, word shape e.g. ‘mysteries’ for ‘mysterious’ or meaning e.g. ‘lake’ for ‘tree’ are all coded under the one category of substitutions yet may represent deficits of decoding, syntax, visual processing or semantics respectively. Similarly part-word omission or addition errors may be tallied as a substitution or a mispronunciation depending on the product and the ‘omission/addition’ information is therefore lost.

Further research is of little value unless studies subtype less-skilled readers and readers with dyslexia into groups with primary deficits in phonological decoding, irregular word reading or weak linguistic abilities and compare these findings with students with combined deficits (Walker, Shinn, Cranford, Givens & Holbert, 2004). Moncrieff (2001) has also expressed the need for documentation on sub-typing of dyslexia and readers with APD. For instance, she expects that eventually it will be possible to profile auditory processing and predict which children will be diagnosed with phonological dyslexia. The reverse may also be possible: to profile reading errors and predict which children have auditory processing deficits. Using the computational connectionist model, Plaut et al. (1996) were able to replicate the reported error pattern of poor readers with language impairments by restricting access to semantic information, demonstrating the potential of error analyses to achieve subtyping.

The skill areas of auditory processing, vocabulary, phonological awareness and rapid naming are often researched in isolation, when it is apparent that there is tremendous interplay as these skills develop. There is a need for a comprehensive error analysis schema that accounts for all word error types including visual confusions e.g. reversals, phonological decoding errors (resulting in mispronunciations), all types of substitution errors, part-word omissions, part-word additions, refusals as well as text error types including losing place in text, whole word omissions, whole word additions, use of recasting (re-reading text portions to assist meaning) and information about self-correction. Additional information about whether meaning has been lost or retained by the error assists understanding about which individuals will have greater difficulty with comprehension. This has been attempted as part of this research, following the principles outlined by McGuiness (1997) who stated that:

> Errors must be phonetically transcribed by the tester into an accurate representation of the child's utterance. Once errors are coded, each error must be classified according to a system that is both mutually inclusive and mutually exclusive. This means that nearly every error can be coded, and there is minimal disagreement about which category the error is coded into (no categorizing system will ever be perfect). (p.122)

2.8 Summary

2.8.1 Significance of the Study

Competent literacy is highly valued in developed countries. Proficient reading is linked to specific life outcomes including academic achievement, employment, housing, economic status, health and relationships (Lyon, 2001) .

The first National Assessment Programme - Literacy and Numeracy (NAPLAN) testing was conducted in Australia in 2008. In all Australian states, students in Years 3, 5, 7 and 9 attending government schools were assessed on the same tests across the same three-day period. Results are determined to be below, within or above the minimum standard band. Performance below the minimum standard band is described as needing " focused intervention and additional support to help them achieve the skills they require to progress in schooling" (Ministerial Council on Education Employment Training and Youth Affairs, 2008, p. 3). The most recently reported data for 2008 shows a 6.1% mean failure to reach the minimum standard for reading in Year 3 and a 7.5% mean failure to reach the minimum standard for reading in Year 5 nationally. Around the states of Australia, the figures for 2008 range from approximately 2 to 11% failing the reading minimum standard in Year 3 and approximately 4 to 11% failing the reading minimum standard in Year 5, with the exception of Northern Territory where failure rates are as high as 36% overall, due to a large gap between indigenous and non-indigenous literacy achievement (Ministerial Council on Education Employment Training and Youth Affairs, 2008). These results are of great concern as reading research has shown that students who do not attain fluent reading by Years 3 or 4, will experience reading difficulties persisting into adolescence (Stothard et al., 1998) and adulthood (Lyon, 1999, 2001). Of children labelled with a reading disability in Year 3, 74% had a reading disability in secondary school (Lyon, 1999).

In Australia, the state of New South Wales currently allocates about $105 million annually towards teaching of students with learning difficulties in 2005 (Office of Financial Management, 2005). The state of South Australia budgeted $35 million towards improvement of literacy outcomes across four years (South Australian Government, 2004-2005). In the United States, special education funding amounted to around $25 billion in the 1999-2000 school year. Nearly half of the special education funding was directed to students with reading difficulties (The Advocacy Institute, 2002).

The cost of poor literacy is not purely financial. In his statement to the sub-committee on education reform, Lyon (2001) outlined that the consequences of a lack of proficient reading ability include social isolation, limited academic success, restricted access to information, reduced career opportunities with detrimental effects for health, safety, relationships, economic power and standard of living. He stated that reading difficulties pose the single most significant cause of academic failure and have also been linked to truancy, poor school retention rates, substance abuse and generally poorer outcomes, including incarceration for criminal behaviours. In the United States, workforce studies of basic literacy skills assessment have shown that 34.1% of job applicants did not have the literacy skills necessary for the position they sought. As a consequence 84.6% of those job seekers were not hired for the positions they sought (American Management

Association, 2001). This provides evidence of the effect of poor literacy on career opportunities and the importance of research which aims to understand the aetiology of poor literacy.

In light of the above concerns the following brief overview of relevant research findings highlights the significance of the present study:

1) a 55% co-morbidity of AP deficits in students requiring special education assistance in one US study (Domitz & Schow, 2000);
2) all students with reading disorder (n = 23; 8-12years) failed at least one test on AP battery including frequency discrimination, dichotic listening, temporal resolution, background noise (Sharma et al., 2006);
3) AP deficits were found in dyslexic subjects include temporal resolution, frequency discrimination, temporal order judgement and PWM (Heiervang et al., 2002; Fischer & Hartnegg, 2004);
4) PWM is significantly poorer in poor readers (Mann et al., 1980; Siegel, 1988) and has been significantly correlated to performance on National Literacy testing in the UK at 7 and 14 years of age (Gathercole, Pickering, Knight et al., 2004);
5) PWM and speech discrimination of poor readers is more significantly affected by noise than good readers (Mann et al., 1980; Brady et al., 1983);
6) poorer PWM found in APD group with concomitant language and reading difficulties (James et al., 1994) and 67% of students with weak PWM scored greater than one standard deviation below average on reading ability (Alloway et al., 2009).

Consequently, the literature reviewed strongly indicates that AP deficits, including PWM deficits, are implicated in language and reading difficulties. The purpose of the present study is to investigate the interaction of AP deficits and reading ability, including reading error types.

2.8.2 The Present Study

This study investigated the auditory processing ability, phonological working memory, receptive language and reading abilities of students aged 8 to 11 years with a known auditory processing disorder (APD). The underlying assumption of the overall study was that if auditory processing skills are implicated in reading development then students with a known APD should exhibit reading difficulties. Study One compared the receptive language and reading abilities of two groups of students. The first group of students was diagnosed with APD (APD group; n = 28) and the second group did not meet the criteria for APD, forming the non-APD group (NAPD group; n = 20). As both the APD and NAPD groups had been previously assessed for the presence of APD, this allowed differences in auditory processing ability, phonological working memory, receptive language and reading ability to be compared across two diagnostically distinct groups. Correlations between AP tests and both receptive language and reading abilities were explored within groups and the effect of severity of AP deficits upon language and reading performance was also analysed. The NAPD group was referred for auditory processing assessment for the same reasons as the APD group, including perceived academic under-performance, and so it was likely that this group would also exhibit reading difficulties. A second study was therefore designed to compare the reading performance and reading errors of the APD group to a group of average readers, but it was not economically feasible, in terms of laboratory time, to perform a complete battery of auditory processing assessments for the average readers.

In Study Two the receptive language and reading performance of a sub-group of students with APD (APD group; n = 21) was compared to a group of average readers without APD (Average group; n = 21) matched for reading age, gender and socio-economic status. The average readers were screened for auditory processing ability. The pattern of reading error types of the APD group and the average readers was analysed and compared. The reading-age matched design endeavours to explore whether the APD readers are simply analogous to a younger reading-age matched group or whether they exhibit a different pattern of reading errors to the reading-age matched group.

The design of the investigation of reading ability allowed exploration of phonological working memory ability, auditory processing ability and receptive language ability in addition to reading performance on a range of reading tasks. The major research questions are firstly: Are AP deficits related to receptive language and/or reading ability? and secondly: Do students with diagnosed AP deficits demonstrate distinguishable reading error patterns? This study has the potential to make a contribution to the body of research in the areas of auditory processing, language abilities and reading ability. These areas are relevant for speech pathologists, audiologists, psychologists, linguists, medical practitioners and educators.

2.8.3 Specific Aims and Hypotheses

The aims of the study were to provide a greater understanding of the effect that auditory processing deficits have upon receptive language and/or reading ability and to investigate the role of phonological working memory and/or language ability upon reading ability. The relationship between severity of AP deficits and both receptive language and reading ability were also explored as a logical extension. Finally, quantitative and qualitative differences in the reading errors made by students with a diagnosed APD compared to the students without APD and the students representing average reading ability were also investigated.

The hypotheses were as follows:

Study One

- Hypothesis 1: the APD group will exhibit significantly poorer auditory processing ability, receptive language ability and reading ability compared to the NAPD group;

- Hypothesis 2: the APD group will exhibit a relationship between the *degree* of AP deficits (severity measure), receptive language ability and reading ability;

- Hypothesis 3: the APD group (n = 28) will exhibit a relationship between auditory processing ability, receptive language ability and reading ability;

- Hypothesis 4: the APD group will show differences in reading error patterns compared to the NAPD group;

Study Two

- Hypothesis 5: the APD group will exhibit significantly poorer receptive language ability and reading ability compared to the Average group;

- Hypothesis 6: the APD subgroup (n = 21) will retain a relationship between auditory processing ability, receptive language ability and reading ability (as per Study One);

- Hypothesis 7: the APD group will show differences in the reading error patterns compared to the Average group.

CHAPTER THREE

Method

The research is divided into two studies. Study One compares the oral language and reading performance of students diagnosed with APD (n = 28: aged 8;3 to 11;0) to a group of students without APD (n = 20: aged 8;0 to 10;6). Subsequent to a diagnostic battery of auditory processing tests potential differences between the group means were compared on a range of tests, including receptive vocabulary, listening comprehension, word identification, word attack skills, reading accuracy, reading comprehension and reading rate. A further aim of Study One was to show the effect of the *degree* of auditory processing deficits on oral language and reading ability.

The main aim of Study Two was to compare the oral language and reading ability of a sub-group of students diagnosed with APD (n = 21: aged 8;3 to 11;0) to a group of Average readers without a diagnosis of APD (n = 21: aged 7;5 to 10;5) who were matched for reading age. In Study Two the reading error patterns of these two groups were compared as well. Data collection for Study One was completed in the state of South Australia while the Average reader data for Study Two were collected in the state of Queensland, Australia.

3.0 Study One

3.1 Group Assignment Procedure

Participants were recruited from the clinical database of the Flinders University Audiology service and a private audiology clinic in metropolitan Adelaide, South Australia. The private clinic was selected because it was known to use the same assessment procedures and diagnostic criteria as the Flinders University service. Participants underwent the standard clinical procedures within the Flinders University Audiology Clinic and the private clinic prior to the study. The procedures require parents and classroom teachers to complete separate questionnaires prior to auditory processing assessment (see Appendices B & C). The questionnaires explore the academic progress, speech and language history and status, listening and attention abilities, auditory memory and the general behaviour of the child. The responses on the questionnaires provide information regarding the child’s functioning at home and in the classroom. Past reports from speech pathologists or psychologists are also requested. The information from the questionnaire and past reports assist the audiologist to discern how related factors such as intelligence, attention, language, fatigue, environmental conditions or motivation may influence the child’s performance on the auditory assessments (Jerger & Musiek, 2000). AP testing is not usually conducted with students with a known intellectual deficit, as the effects of cognitive deficits would invalidate the results. The response information is taken into consideration at the time of diagnosis of APD. For instance, the audiologist may ascertain that while audiological results confirm a diagnosis of APD, the child appears to have significant concomitant or co-morbid factors such as attention deficits, language deficits, fatigue or motivational issues that may be affecting the purity of the results. A skilled audiologist aims to mitigate fatigue and motivation and determine when other factors may be contributing to a false positive outcome. Further investigation and interventions regarding these other factors are likely to be recommended. Responses that indicate observations such as difficulties with sustained listening, better performance in ideal listening conditions (e.g. one-to-one interaction, quiet room) or apparent average intelligence yet poor academic performance are consistent with the APD diagnosis.

The standard AP assessment protocol used at the Flinders University audiology clinic is composed of the examination and battery of AP tests described in the following section[5]:

- Otoscopy (physical examination of ear health)
- Pure tone audiometry (peripheral hearing acuity)
- Speech audiometry (AB word lists) – (Boothroyd, 1982)
- Staggered Spondaic Word (*SSW*) test – (Katz, 1977)
- Competing Sentences (*CS*) test – (Willeford, 1977)
- Digit Span *(DS)* test- (Sanchez, 1989)
- Sentence Recall *(SR)* subtest – (Spreen & Benton, 1977)

---

[5] Prior to the study, the normative data for the AP battery were gathered from 175 Adelaide metropolitan primary school students aged between 7 years 0 months and 10 years 11 months by an academic audiologist from the Flinders University Audiology Clinic over a twelve-month period in 1988-1989 (see Appendix X for data collection procedure). The inclusion criteria for the normative sample were:

- Peripheral hearing within normal limits
- Current year level of schooling commensurate with chronological age
- Not considered by class teacher to have a learning disability
- Not thought to evidence behaviours known to be typical of APD on a checklist completed by the class teacher and the parent
- English as a first language

All hearing and AP tests are administered via headphones in a sound-proof room with the exception of Sentence Recall, which is administered via live voice in free field, in the same setting. With the exception of this latter test, the tests were presented using a high fidelity CD player (Pioneer Model PDS-505: Hi-Bit Legato Link Conversion) routed via a calibrated dual channel digital speech audiometer (Interacoustics AC30). For all participants, AP testing was performed once pure tone audiometry showed hearing acuity to be within the normal range as per the usual protocol, described in section 3.1.2 below. Sample score forms for the AP battery are contained in Appendix D.

3.1.1 Otoscopy

The external auditory meatus (outer ear canal) and tympanic membrane (eardrum) are examined to determine an unoccluded canal, health status of the outer ear and the integrity of the eardrum. Additional information regarding the status of the middle ear can be gleaned from the colour and position of the semi-transparent eardrum.

3.1.2 Pure Tone Audiometry

Auditory signals typically contain temporal, intensity and frequency dimensions. Pure tone audiometry evaluates the frequency and intensity dimensions, by requesting confirmation of a tone being detected. Tones are presented in the following order of frequencies: 1kHz, 2kHz, 4kHz, 8kHz and 500Hz, typically firstly to the right ear and then the left ear. The stimulus at each frequency is delivered firstly at 40dB and then decreased in 10dB increments until a nil response is returned. The intensity is then increased by 5dB and if a positive response is received, is again lowered by 10dB. This ‘minus 10 and plus 5’ procedure continues until a consistent response is received and this is recorded as the hearing threshold level at this frequency. A normal hearing result occurs when all test frequencies are heard at 20dB or lower in both ears i.e within the range of -10dB to +20dB, in accordance with the International Organisation for Standardisation (Martin, 1986). Results outside this range indicate peripheral hearing impairment for the detection of sound. The hearing impairment may be caused by a range of disorders or changes affecting the outer, middle and/or inner ear. One or both ears may be affected.

3.1.3 Speech Audiometry

Speech discrimination testing is another measure of peripheral hearing. For this purpose, Arthur Boothroyd (1982) devised the phonetically balanced AB wordlists. Phonetically balanced wordlists represent the range of phonetic combinations of a language in the proportion that they are represented in the language (Martin, 1986). The words are monosyllabic real words, delivered monaurally one word at a time at 30dB Sensation Level (SL), using a recording by an Australian speaker. Sensation level is the level above the average of the examinee’s three pure tone thresholds for 500Hz, 1kHz and 2kHz for each ear. In order to be successful on this test, the listener must be able to detect the signal, discriminate the word and repeat the word. Successful repetition of 90% of the words or greater is expected when hearing is normal. A result matched with this expectation supports normal peripheral hearing status. A poorer than expected result may indicate functional difficulties with speech perception, indicating the need for further investigation.

3.1.4 Auditory Processing Assessments

A dysfunction along the auditory nerve or at the cortical level cannot be detected by pure tone audiometry or speech discrimination testing. Evaluation of central function requires manipulation of one or more of the temporal or spectral dimensions of the signal delivered either monaurally, binaurally or dichotically (Berlin & Lowe, 1972). Frequency information is tonotopically organised along the basilar membrane of the organ of Corti in the cochlea. Normal neural transmission of speech dimensions via the auditory nerve commence at the spiral ganglion of the cochlea. There are different pathways of sound transmission, designed specifically for sound localization and sound identification (Eggermont, 2001). Temporal and intensity level differences for each frequency travel ipsilaterally via the anterior ventral cochlear nucleus, lateral lemniscus and superior olivary complex to the inferior colliculus and proceed to the auditory cortex. Comparison of this information about timing and intensity arriving in the two cortices allows sound localization. Spectral aspects or across frequency timing aspects such as frequency contours, vowel harmonicity, gaps, voice onsets and offsets, frequency and amplitude modulation depart the ipsilateral posterior ventral nucleus and then travel contralaterally via the lateral lemniscus to the inferior colliculus and medial geniculate body before arriving at the auditory cortex. At the inferior colliculus a frequency-specific (tonotopic) map is constructed for sound identification that is then conveyed to the auditory cortex (Eggermont, 2001). Each sound must be preserved accurately and in sequence with other sounds to construct a neural representation of the verbal message. Verbal information received in the right auditory cortex crosses the hemispheres at the cortical level via the corpus callosum for linguistic processing in the left hemisphere. Figure 6 displays a block diagram of the auditory pathways.

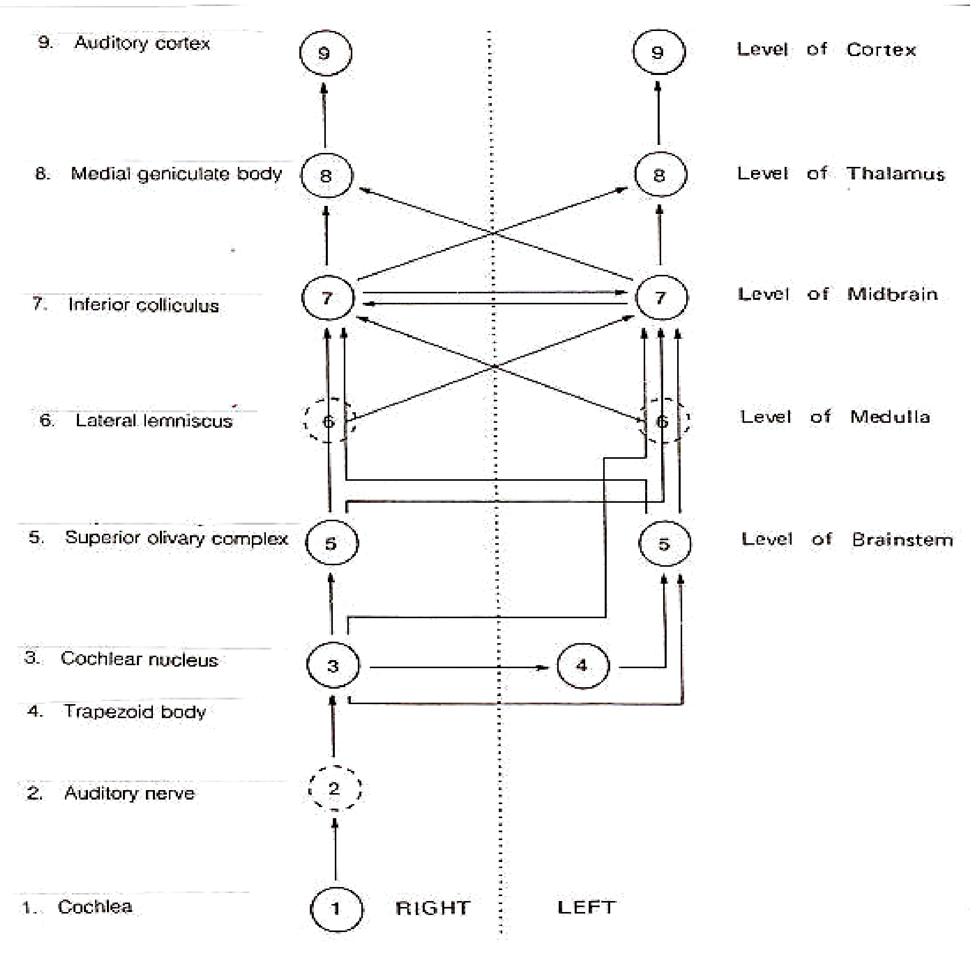


FIGURE 6: Block diagram of the auditory pathways [6]

In summary, the normal listener is able to make use of the information to differentiate two signals, localise sound or separate a target signal from

---

[6] (Martin, 1986, Introduction to Audiology, Figure 9.1 'Block Diagram of the Auditory Pathway', p.306. reprinted with permission of Pearson Education, Inc.)

background noise. The auditory processing battery used by the Flinders University Audiology Clinic (and the private clinic) is composed of two tests of dichotic listening (the *Staggered Spondaic Word* test and *Competing Sentence* test) and two tests of auditory short-term memory (*Digit Span* test and *Sentence Recall* test). This study will refer to this test battery as the FUSAPB: the Flinders University standard auditory processing battery.

Valid assessment requires the assessment tools to be appropriately sensitive and specific. Sensitivity refers to a test indicating a deficit when a deficit does exist (Chermak & Musiek, 1997). A test needs to be sufficiently sensitive to detect deficits without being too sensitive, resulting in false positives. It is worth noting that individuals with APD are a heterogeneous group and therefore, there is an argument that any one AP test will not be sensitive for an accurate diagnosis of APD, yet still be sensitive for the auditory skill which it was designed to test (Medwetsky, 2002b). Consequently, referred individuals may show deficits in some auditory processing skills but not others. This position lends weight to the importance of a test battery approach. The tests should also have high specificity. Specificity refers to the ratio of individuals who do *not* have an AP deficit and achieve a negative result compared to the total number of individuals who do *not* have AP deficit in the sample, regardless of their result i.e. a true negative result (Working Group on Auditory Processing Disorders, 2005). As sensitivity to a deficit increases, the likelihood of false positives also increases, thus lowering specificity. The ideal of sufficient sensitivity and high specificity can be difficult to achieve, but is one of the important factors considered in the construction of a clinical AP test battery. Where known, sensitivity and specificity data is given in the description of each test in the FUSAPB.

Dichotic tests involve different information being delivered to each ear simultaneously (or in overlapping time) and a response requiring the examinee to separate the information being delivered to one ear only or to integrate the information being delivered to both ears. Dichotic assessments should only be administered to individuals with bilaterally symmetrical hearing, as assessed by pure tone audiometry (Bellis, 2003). When the response requires the information to be combined this is called binaural integration; if the information must be separated this is called binaural separation. Valid measures of dichotic listening are considered an essential component of AP assessment due to their sensitivity and specificity in detecting auditory processing dysfunction (Jerger & Musiek, 2000; Katz, 2002; Medwetsky, 2002b; Bellis, 2003).

Dichotic testing is designed to challenge both the auditory cortices and the pathways between them, crossing the area known as the sulcus within the corpus callosum. Speech and language processing occurs predominantly in the left hemisphere. As previously mentioned, the majority of the linguistic information received by the right ear crosses to the left hemisphere for processing. Linguistic information delivered to the left ear crosses to the right hemisphere but must then return to the left hemisphere via the corpus callosum for processing. The corpus callosum is one of the last cortical structures to become fully myelinated and therefore functionally mature (Medwetsky, 2002b). Therefore, the stronger ear is opposite to the dominant hemisphere for speech and language, due to the greater amount of auditory information that crosses to the opposite hemisphere. Consequently, until about 11 to 13 years of age, linguistic information delivered to the right ear is processed more efficiently than information delivered to the left ear (Pinheiro & Musiek, 1985a). This results in what is referred to as the right ear advantage (REA). The REA is well reported in the literature and refers to the expected better performance of the right ear on dichotic language tasks (Brunt, 1972; Geffner, 2005). Consequently, the normative data reflect higher expectations for the right ear. While a REA is normal, a greater than expected REA signifies immaturity of the corpus callosum. That is, linguistic information delivered to the left ear is not efficiently crossing back to the left hemisphere via the corpus callosum. When this occurs it can be assumed that there will be a disparity in the arrival time of linguistic information to the language processing areas in the temporal and parietal lobes. This is a disorder of interhemispheric transfer, and is hallmarked by significantly poorer performance on testing for information delivered to the left ear.

Both dichotic tests in the test battery, the *Staggered Spondaic Word* test and the *Competing Sentences* test, were originally designed for use in the adult population and have been shown to discriminate between lesions sited in the auditory nerve, auditory brainstem or auditory cortex in adults (Willeford, 1985; Wilson, Katz, Dalgleish & Rix, 2007). Both tests have been linguistically adapted and normed for use in the child population.

3.1.4.1 Staggered Spondaic Word (SSW) test

The *Staggered Spondaic Word (SSW)* test (Katz, 1977) is a dichotic test of binaural integration. In total, 40 spondees (words) are presented at 50dBSL to both ears, as 20 stimulus pairs. Each spondee is a two syllable compound word presented to one ear such that the second syllable of the first word overlaps with the first syllable of the second word presented to the other ear e.g. day*light-lunch*time, whereby ‘light’ and ‘lunch’ are presented simultaneously as the competing dichotic condition. The syllables ‘day’ and ‘time’ are non-competing stimuli and represent the non-competing condition. Each stimulus pair is presented alternately to the left ear first and then the right ear first, via headphones. The examinee is requested to repeat *both* words for all 20 stimulus pairs i.e. integrate the information about each word from the received input about both words. The pairs are scored as to whether the syllables heard in the non-competing conditions and competing conditions were correct for each ear. The number of *errors* is then converted to a percentage e.g. 3 errors are recorded as 15%. The result is an error percentage for each of the 4 categories: right non-competing (RNC), left non-competing (LNC), right competing (RC) and left competing (LC). The error percentage is then compared to the normative data. For the statistical purposes of this study, the error percentage was converted to a *correct* percentage and converted to a standard score.

The *SSW* test has for many years been considered to be one of the most valid and reliable instruments for assessment of interhemispheric transfer of auditory information (Katz, 2002; Bellis, 2003). The words presented to the right ear pass to the language processing regions in the left hemisphere, but words presented to the left ear pass to the right hemisphere and must cross the corpus callosum for processing in the left hemisphere. Katz (1982) reports that normally functioning children above 8 years of age and adults can usually repeat both words without difficulty (Arnst, 1982). Therefore a lowered performance in either or both ears or in a particular condition (competing or non-competing) is meaningful.

During test development, Katz took into consideration many factors including peripheral hearing (by use of sensation level for presentation), the effect of language ability as well as the ease of training the examinee (Brunt, 1972) to ensure validity of the test. Familiar words were selected to reduce linguistic load and therefore maximize assessment of auditory processing, rather than vocabulary. However, while this was undoubtedly true at the time of test development, it must be acknowledged that some of the items are now culturally dated e.g. 'corn-bread', 'wash-tub'. Nevertheless any language interference should be equally distributed across the conditions and participants (Katz & Tillery, 2005). If a high number of errors occur in all conditions, including the non-competing condition, this is indicative of speech discrimination difficulty (Arnst, 1982) or language interference as previously mentioned. Average scores (or above) in a competing condition indicate the integrity of Heschl's gyri (auditory cortices), upper brainstem or corpus callosum. A score below the average range indicates possible dysfunction in the interhemispheric transmission of information via the corpus callosum (Arnst, 1982). Cortical involvement is reflected in the contralateral ear score whereas brainstem or corpus callosum involvement will be reflected in the ipsilateral ear score. Particular difficulty in the LC condition, compared to RC condition results, is an indicator of inefficient interhemispheric transfer of information via the corpus callosum (Medwetsky, 2002b). Low scores for both the LC and RC conditions suggest difficulties with divided attention. Depressed RNC and/or RC scores on any profile are suggestive of language processing difficulties. Lower than expected scores in both RNC and LNC conditions may indicate poor fast mapping ability (refer pp.122-123) for words isolated out of context. The *SSW* test is considered superior in terms of sensitivity, specificity and standardisation compared to many other tests designed for similar purposes, such as the Rapidly Alternating Speech Perception test (RASP), the Low-Pass Filtered Speech test and Binaural Fusion test (Wilson et al., 2007).

Musiek, Geurink and Kietel (1982) evaluated the sensitivity of seven AP tests, including the *SSW* on a sample of 22 children aged 8 to 10 years considered to have auditory processing difficulty. Sensitivity of 50% for the *SSW* test was found in this population and left ear performance was lower than right ear performance, though not significantly so. Mueller, Beck and Sedge (1987) reported a higher sensitivity of 66% and specificity of 67% on the *SSW* test. Singer, Hurley and Preece (1998) investigated the sensitivity and specificity of the *SSW* across five age bands from 7 to 13 years and found lower sensitivity results than these previous researchers, with an average sensitivity of 31%. However the average specificity or true negative on the *SSW* was 92% with a false positive rate of 10% for 8 year-olds, 12% for 9 year-olds and 11% for 10 year-olds. Therefore while sensitivity on the *SSW* is not ideal, specificity is strong. Singer et al. (1998) consequently emphasized the importance of a battery approach to auditory processing assessment.

Poor performance on the *SSW* test may indicate difficulty with interhemispheric transfer of the acoustic signal, auditory discrimination (lexical decoding), divided attention to the two stimuli in the competing condition or short-term auditory memory depending on the pattern of results (Smoski, Brunt & Tannahill, 1992b). If interhemispheric transfer of information is not efficient this would mean that acoustic information arriving at both ears in the normal listening situation is not arriving at the left hemispheric language areas simultaneously, potentially resulting in a degraded version of the input which is likely to affect speech discrimination, auditory short-term memory and language processing. The effects would be exacerbated by additional background noise input. For the purposes of this study, the information regarding the integrity of the auditory system makes the *SSW* a valuable inclusion in this study.

3.1.4.2 Competing Sentences (CS) test

The *Competing Sentences (CS)* test (Willeford, 1977) is a dichotic test of binaural separation. A sentence pair is presented simultaneously, one to the left ear, one to the right ear (via headphones). Essentially, the ears are in competition with each other. The examinee is asked to provide the sentence heard in the target ear only. This is achieved by suppressing the information received by the non-target ear and directing attention to the target ear information. Twenty pairs of sentences of similar length and content are presented, as a set of 10 to each target ear. The sentences are described by Willeford (1985) as deliberately semantically competitive. The target ear receives a sentence at 35dBSL (e.g. 'There is a car behind us') and the competition ear receives a sentence at 50dBSL (e.g. 'This road is very slippery'). Thus, the target sentence is presented at a minus 15dB signal-to-competition ratio. The *CS* is scored according to the number of sentences correct for each ear, converted to a percentage correct. To be correct, the sentence must not contain elements from the competing sentence and must be considered a 'reasonable approximation' of the target sentence. The higher score is then assigned the 'strong ear' label (*CS-S*) and the weaker score is assigned the 'weak ear' label (*CS-W*).

The *CS* is considered a valid and reliable measure of dichotic listening, evaluating binaural separation (Katz, 2002; Medwetsky, 2002b; Bellis, 2003). Children as young as 5 years of age are able to achieve a score of 100% without competition and therefore the *CS* is not considered a test of phonological working memory. Normative data show that a 6 year old child will achieve a score of 90-

100% in the right ear, with a 40% difference in the left ear under dichotic conditions. The left ear score continues to improve until 100% is typically achieved at about 11 years of age (Keith, 1984). Individuals with APD typically have much greater difficulty with the task and this is considered to be due to processing overload (Medwetsky, 2002b). The clear right ear advantage shown in individuals without APD and the difficulty shown in individuals with APD led Keith (1984, p. 10) to conclude that "sentence materials with their heavy linguistic load, may be the most appropriate stimuli for assessing hemispheric function in children".

In the review of the sensitivity of seven AP tests by Musiek et al. (1982) the *CS* was found to be the second most sensitive test to auditory processing dysfunction of the tests evaluated. Eighty-six percent of the 22 children aged 8 to 10 years suspected to have AP difficulties failed this test. The children also showed a significantly poorer performance for the left ear compared to the right ear on the *CS*, demonstrating that the *CS* is sensitive to difficulties with interhemispheric transfer of auditory information. Domitz and Schow (2000) found a 100% specificity and 0% false positive rate, with a sensitivity of 25% and 75% false negative rate for the *CS*. Therefore, while the *CS* may not detect all individuals with interhemispheric transfer difficulty one can be confident about the presence of a deficit in those positively identified.

In natural situations, spoken information is not delivered separately to each ear. However, poor performance on the *CS* may indicate difficulties with binaural separation or selective listening as a result of dysfunction in auditory attention to a target. Poor performance suggests that separation of the two acoustic signals (speakers' voices) is effortful which may indicate difficulty with auditory discrimination of speech and auditory attention. Significantly poorer results for the left ear compared to the right ear indicate a difficulty with interhemispheric transfer of linguistic information (Medwetsky, 2002b). Again, the presence of background noise would make the listening situation fatiguing for individuals with interhemishperic transfer difficulties. As a result of poorer quality input language may be perceived as 'jumbled' and the subsequent processing load has possible consequent effects including poorer phonological working memory (for larger amounts of information), poorer quality of stored phonological representations or quantity of semantic representations, poorer language development and potentially, poorer reading comprehension. Due to the high specificity to interhemispheric transfer performance, the results of the *CS* test are a useful inclusion in this study.

3.1.4.3 Digit Span (DS) test

Standardized measures of auditory short-term memory are also considered strong indicators of auditory processing ability and are highly predictive of classroom performance in terms of both literacy achievement and listening behavior (Rowe, Rowe & Pollard, 2004).

The auditory *Digit Span (DS)* test (Sanchez, 1989) is primarily a test of auditory short-term memory for material presented as an unsequenced number series. The examinee is required to repeat the series of digits (numbers) in presentation order. The digits are presented bilaterally, under headphones, at a comfortable listening level, usually 50-55dB. The *DS* test used in the Flinders University and private clinic test battery was recorded in Australian voice at the rate of one digit per second. In sets of three, the items increase in series length from two digits to a maximum of seven digits. Testing ceases when a ceiling of three consecutive incorrect items is reached. The score is recorded as the longest correct digit series correct e.g 4 numbers = score of 4. Details of the normative sample plus data are provided in Appendix E.

The *DS* test aims to measure the amount of spoken information that can be held in short-term memory and repeated in sequence (Wechsler, 2003). The purpose of the *DS* test is to measure the short-term repository of verbal information in a task that does not *require* access to meaning in order to be successful. Consequently, the term ‘unrelated’ material is often used for the *DS* test. However, it is not possible to separate numbers from their representation of quantity, numerical sequence or numerical patterns.

The ability to repeat a series of digits has been significantly correlated with age ($r = 0.377$, $p<0.05$) reflecting increased short-term memory and phonological working memory with maturation (Metsala, 1999). At four years of age children are normally able to repeat three to four digits successfully while adult levels of seven or more digits are normally obtained around fourteen years of age (Gathercole & Baddeley, 1993). Digit span tests are commonly used within intellectual assessments such as the Wechsler Intelligence Scales for Children–4 (WISC-4) as a measure of short-term auditory memory, but also auditory attention (Wechsler, 1974, 2003). While poor performance on the *DS* test indicates poor short-term memory capacity, it can also indicate poor attention or sequencing difficulties. Sequencing difficulties can be detected by qualitative analysis of the responses to determine if the correct digits were provided, out of order. Differentiation of auditory short-term memory vs. auditory attention is more difficult, but responses are usually more erratic with some items correct within a set of three sometimes accompanied by correct set of items at a higher level when auditory attention is poor or fluctuating.

If less information can be held by short-term memory, less information can be fed to the phonological loop for phonological and linguistic processing and ultimately to phonological and semantic representations in long-term memory. Consistently reported findings that auditory short-term memory is poor in poor readers (Gathercole & Baddeley, 1993) makes the *DS* test a valuable inclusion in this research.

3.1.4.4 Sentence Recall (SR) subtest

The *Sentence Recall (SR)* is a subtest of the Neurosensory Center Comprehensive Examination for Aphasia–NCCEA (Spreen & Benton, 1977). The *SR* test is a test of PWM for related or meaningful material. The examinee is required to repeat sentences presented via live voice at conversational level (55-60 dB) in a sound-proof room. Sentences commence with a one syllable word (i.e. ‘Look’) and increase in length to a maximum of 20 words containing 25 syllables in total. Administration ceases when two consecutive items are incorrect. Basal scores (*SR-B*) representing the highest item number before the first error and ceiling scores (*SR-C*) representing the last correct item number before two consecutive incorrect responses are recorded. The item number is not equal to the number of words or syllables in the sentence.

Verbatim recall of lengthy sentence material challenges PWM capacity (Gathercole & Baddeley, 1993). The length of the items in the *SR* test extends beyond the amount of information that can be repeated without accessing long-term memory. Stored linguistic and/or episodic memory is activated to categorise or chunk the auditory input in the phonological loop. Tests of sentence recall are often considered to be a measure of phonological processing within working memory i.e. phonological working memory (Share & Leikin, 2004) and have been used as such in the research (Mann et al., 1984; Bowers et al., 1988; Montgomery, 2003; Oakhill et al., 2003).

Tests of sentence recall are frequently contained within language assessment batteries. For instance, the Clinical Evaluation of Language Fundamentals (CELF) contains the *Recalling Sentences* subtest. This subtest has been found to have sensitivity of 90% and specificity of 85% for the detection of language impairment (Conti-Ramsden, Botting & Faragher, 2001). A sentence recall task was able to discriminate between language impaired and typically developing Cantonese speakers with a sensitivity rate of 77% and specificity rate of 97% (Stokes, Wong, Fletcher & Leonard, 2006). Such high levels of sensitivity and specificity for alternative measures of sentence recall make the *SR* test a valid inclusion in the AP battery.

If either component of PWM, the phonological store or the phonological loop, is weak then the examinee is likely to omit sections of the sentence or paraphrase the meaning of the sentence. Consequently, the *SR* test evaluates the integrity of both language processing and PWM abilities. For this reason, sentence repetition tasks are also used in assessment of language disorders in children and adults, including aphasia, in addition to the assessment of auditory processing (Semel, Wiig & Secord, 1995). Performance on the *SR* is likely to be indicative of the *amount* of information available for listening comprehension and able to be transferred to long-term memory.

In summary, the two tests comprising the dichotic listening component of the AP battery evaluate whether auditory processing skills requiring integration or separation of information travelling via the left and right auditory pathways are intact and the two tests comprising the auditory memory component of the battery evaluate short-term memory for digits and PWM for sentence material. When a child’s performance scored equal to or greater than two standard deviations below the age mean on two or more of the tests (including at least one test of dichotic listening) within the test battery, an auditory processing disorder (APD) was diagnosed.

3.2 Recruitment Process

In total, one hundred and eighty six families were approached, one hundred and forty-eight families on the clinical database of the Flinders University Audiology service and thirty eight families from the private audiology clinic. The parents of prospective participants were sent an information sheet with an invitation to participate (see Appendix F). All participants had been referred to the Flinders University Audiology service or the private audiology clinic for auditory processing assessment by a psychologist, speech pathologist or paediatrician. The main reasons for referral to the audiology clinics included observed and/or reported poor listening, frequent mis-hearing, difficulty hearing in background noise, difficulty following instructions and/or inattention, typically accompanied by perceived under-achievement in academic areas.

Prospective participants who returned an expression of interest were contacted by phone and if willing to proceed, they were then forwarded a consent form plus questionnaire and two one-hour appointment times were arranged (see Appendices G & H). The inclusion criteria were stated in the invitation to participate in the research and were further substantiated via the questionnaire described in the next section.

The inclusion criteria for participants were:

- non-verbal intellectual abilities falling within the average range or higher on the measure described in the data collection procedure
- English as the first language
- hearing acuity likely to be within normal limits, determined by the screening test described in the data collection procedure
- no known concerns regarding visual acuity or corrected visual acuity(with glasses)
- no known neurological conditions such as autism, epilepsy, cerebral palsy, neurofibromatosis
- no known history of head injury

Participants with diagnosed attention deficit disorder (ADD) or attention deficit hyperactivity disorder (ADHD) were permitted to participate in the study provided prescribed medication was taken on the days of assessment. Tillery (2005) found an equal prevalence of ADHD in a population with and without APD. In addition, results on the *Staggered Spondaic Word Test (SSW)* have also been found to be unaffected by the stimulant medication methylphenidate (Ritalin) prescribed for ADHD (Tillery et al., 2000). Therefore it was deemed suitable to include participants diagnosed with ADHD in the study.

3.3 Participants

Forty-eight participants were recruited for Study One: 34 males and 14 females, aged between 8 years 0 months and 11 years 0 months at the time of testing for this study. All 48 participants had undergone the standard auditory processing battery (SAPB) provided by one of the two audiology services within 18 months prior to the commencement of Study One. At each of these clinics, APD was diagnosed when a child scores equal to or greater than two standard deviations below the age mean on two or more of the tests within the AP battery. Twenty-eight participants were diagnosed with an auditory processing disorder (APD group); twenty participants did not fulfil the criteria for APD and they constituted the group of non-APD participants (NAPD group). The design allows the oral language and reading abilities of the APD group and NAPD group to be compared. A summary of the two groups is provided in Table 1.

TABLE 1:
Participants according to Group for Study One

APD group (n=28)		**NAPD group (n=20)**		**Total (n=48)**	
Male	Female	Male	Female	Male	Female
18	10	16	4	34	14
Age Range: 8;3-11;0		Age Range: 8;0-10;6		Age Range: 8;0-11;0	

There was no significant difference between either the chronological age (APD mean = 9;4, SD = 7.3 months compared to NAPD mean = 9;3, SD = 9.2 months: *z* = -0.27, p=0.79, ns) or gender composition (X2[df=2] = 1.39, p>0.05, ns) of the APD and NAPD groups. There was also no significant difference between the standard scores on the *Raven's Coloured Progressive Matrices* measure of non-verbal intellectual ability (APD mean = 102, SD = 10.3 compared to NAPD mean = 108, SD = 12.4 : *z* = -1.44, p=0.15, ns) for the two groups.

In accordance with the diagnosis, performance on the auditory processing tests within the FUSAPB was significantly poorer for the APD group compared to the NAPD group as outlined in Table 2, with the notable exception of performance on the *DS* test. Table 3 details the raw results on the FUSAPB for comparison.

TABLE 2:
Mean Standard Scores (X=100, SD=15) on FUSAPB compared by Group.

Test	APD group (n=28) mean (SD)	NAPD group (n=20) mean (SD)	Mann-Whitney U Test	Significance level (p≤ 0.05, 2-tailed)
SSW (LNC)	76.52 (33.79)	100.08 (16.37)	-2.64	p=0.01,S
SSW (LC)	73.65 (14.65)	94.83 (16.27)	-4.07	p<0.01, S
SSW (RC)	74.07 (16.51)	94.06 (11.55)	-4.01	p<0.01, S
SSW (RNC)	66.82 (39.91)	99.38 (13.55)	-3.62	p<0.01, S
CS (S)	58.05 (35.37)	79.07 (33.59)	-2.23	p=0.03, S
CS (W)	55.46 (91.87)	90.34 (25.34)	-2.71	p=0.01, S
DS	82.97 (10.65)	84.78 (10.88)	-0.17	p=0.86, NS
SR (B)	76.60 (19.78)	91.38 (9.74)	-2.67	p=0.01, S
SR (C)	82.32 (17.67)	95.85 (14.87)	-2.62	p=0.01, S

KEY:
SSW = Staggered Spondaic Word test; (RNC) = Right Non-competing condition, (LNC) = Left non-competing condition; CS = Competing Sentences test; (S) = Strong, (W) = Weak; DS = Digit Span test; SR = Sentence Recall test : (B) = Basal, (C) = Ceiling

TABLE 3:
Range, mean and standard deviation on FUSAPB raw scores compared by group.

	APD group (n=28) range	APD group (n=28) mean (SD)	NAPD group (n=20) range	NAPD group (n=20) mean (SD)	Measure
SSW (LNC)	0-55	16.96 (14.62)	0-20	8.5 (5.87)	% Errors
SSW (LC)	20-80	55.36 (16.1)	10-65	36.5 (15.74)	% Errors
SSW (RC)	10-75	45.71 (17.46)	20-55	31.25 (10.5)	% Errors
SSW (RNC)	0-50	15.71 (13.72)	0-25	6 (6.41)	% Errors
CS(S)	20-100	67.86 (21.32)	0-100	76.5 (24.34)	% Correct
CS(W)	0-80	24.29 (23.32)	0-90	42.5 (30.24)	% Correct
DS	3-6	4.36 (0.78)	4-6	4.53 (0.68)	No. Correct
SR(B)	5-14	9 *(2.43)*	8-11	10.2 (1.0)	No. Correct
SR (C)	7-14	10.57 (2.17)	9-14	11.65 (1.57)	No. Correct

3.4 Data Collection Procedure

Parents of the target participants were sent a questionnaire that had been compiled by the researcher and contained questions regarding their child's developmental history, medical history, speech and language development, academic progress and any intervention received. Key questions in the questionnaire were intended to reveal whether:

- there was any family history of known learning difficulty;
- the student had any known reading difficulties;
- the student had received any special education intervention for those difficulties;
- there was any evidence of language or phonological difficulties;
- the student had received any speech pathology intervention for those difficulties;
- the student had experienced any past or present middle ear pathology;
- the student had been diagnosed with ADD/ADHD or any other medical conditions or disorders.

These factors might have an impact on the student's performance on the reading and/or auditory processing tasks and the information was collected for reference. If available, speech pathology, psychological and optometric reports were also requested. Information regarding language abilities, full-scale intellectual performance, vision and visual processing may have relevance to reading performance and so was recorded where known. The information also further substantiated that the participant met the inclusion criteria.

Chi-square analysis showed no significant differences were found between groups on data relating to history of speech and/or language support, current speech and/or language concerns, diagnosis of ADHD or associated current medication, diagnosis of dyslexia or current reading support.

3.4.1 First Assessment Session

The first of two one-hourly sessions was held in a sound-proof booth at Flinders University to:

- collect signed consent;
- review the questionnaire for completeness and clarification;

and administer the following assessments, as described below;

- screen hearing acuity at selected frequencies;
- administer the Raven’s Coloured Progressive Matrices (Raven, Court & Raven, 1995) as a measure of non-verbal intellectual ability

and administer further auditory processing assessments in order, as described below:

- the SCAN-C: A Screening Test for Auditory Processing Disorders; Auditory Figure-Ground Subtest (Keith, 1986); the Pitch Pattern Sequence Test - Child Version (Pinheiro, 1979);
- the Random Gap Detection Test (Keith, 2000).

3.4.1.1 Screen of hearing

Although hearing acuity had been clinically assessed as within normal limits via pure tone audiometry within 18 months prior to the first assessment session as part of the clinical assessment for APD, hearing ability was screened to determine that it was likely this status had not changed. The screening procedure involved presentation of pure tones at selected frequencies in the order of 1kHz, 2kHz, 4 kHz and 500Hz each at 20dB in the soundproof room. As a familiarisation procedure, the 1kHz tone was presented to the left ear first at 40dB, then 30dB before being dropped to 20dB, followed by the remaining frequencies for that ear at 20dB. This procedure was repeated for the right ear. The participant was asked to respond by pressing a buzzer. If a response was not returned on two presentations of the tone at 20dB the intensity level was raised to 30dB and if detected, lowered to 25dB and if detected, lowered again to 20dB. If undetected at 20dB, the threshold for that frequency was recorded at 25dB. The participant was considered to have passed the screening test if all frequencies were detected at 20dB with no more than one frequency detected at 25dB, but not 20dB, across both ears.

3.4.1.2 Non-verbal intellectual ability

As the language abilities of the participants in this study are likely to be varied across the group, measures of intelligence that include verbal performance are also likely to be varied. The *Raven's Coloured Progressive Matrices (RCPM)* was therefore used to exclude individuals with below average, nonverbal intellectual abilities (Raven et al., 1995). On the *RCPM* the stimulus page shows a pattern with one piece missing. Immediately below the pattern are six pieces that fit the shape of the missing piece, each with a different pattern. Examinees are required to point to the piece that would correctly fill the blank space to complete the overall pattern depicted above it. This is tapping the ability to form a ‘consistent theme of thought’, sometimes referred to as a Gestalt, by recognizing the parts that constitute the whole. The test is designed to evaluate the cognitive processes expected in the target age group, based largely on Piagetian principles. These processes include identification of patterns, similarities, differences, orientation and closure as well as the use of analogous reasoning (Raven et al., 1995) . The examinee scores one point for each correct response and the total score is then compared to the normative data. Four potential participants were excluded due to their performance on the *RCPM* falling below the average range.

The retest reliability of the *RCPM* has been evaluated on a number of occasions and found to be in the vicinity of .9 (Raven et al., 1995). The *RCPM* has been shown to correlate with other measures of intelligence such as the Slosson Intelligence Test (r = 0.62 - 0.70), Stanford-Binet Intelligence Scale (*SBIS*) (r = 0.68) and Wechsler Intelligence Scales for Children (*WISC*) (r = 0.41 - 0.91). The *RCPM* consistently correlates more strongly with the non-verbal (performance) scale than with the full WISC scores. In one study of 154 children the correlations were .7 and .5 respectively, though a median correlation of .67 with the full-scale IQ score across studies suggests the *RCPM* is a fairly robust measure of general intelligence. The *RCPM* was not included in this study to investigate a relationship between intelligence and auditory processing, receptive language or reading.

3.4.2 Auditory Processing Assessments - extended

Further auditory processing assessments were included to expand the range of auditory skills evaluated in the participants. Assessments of skills that have been implicated in reading research were sought. In particular, tests of low redundancy (speech-in-noise), frequency discrimination and temporal processing have been linked to linguistic and phonological processing, as discussed in the literature review.

The minimal AP battery recommended by the Consensus Conference on the Diagnosis of Auditory Processing Disorder in School-Aged Children (Jerger & Musiek, 2000) further guided the selection process. The minimal battery includes measures of word recognition or speech discrimination, dichotic testing, pattern sequencing and temporal gap detection in addition to pure tone audiometry (hearing acuity). Tests of speech discrimination (AB word lists), dichotic testing (*SSW* and *CS*) as well as auditory memory (*DS* and *SR*) had already been performed prior to the study. Using the selection guide and the recommended minimal battery, the following tests were selected to target additional aspects of auditory processing:

- the SCAN-C: A Screening Test for Auditory Processing Disorders; Auditory Figure-Ground subtest (Keith, 1986);
- the Pitch Pattern Sequence Test - Child Version (Pinheiro, 1979);
- the Random Gap Detection Test (Keith, 2000).

The above tests were specifically developed and designed for administration to children. All tests were administered in the sound-proof room via headphones.

3.4.2.1 SCAN-C: Auditory Figure Ground (AFG) subtest

The *SCAN-C: Auditory Figure Ground (AFG)* subtest (Keith, 1986) is a monaural separation task. That is, the auditory information is delivered to one ear only at a time. Background noise in the form of multi-talker speech babble is presented to the same ear as the stimulus word presented at +8dB speech-to-noise ratio, at uniform intensity. The *AFG* requires the examinee to listen to a list of 20 words for each ear, spoken against the background noise, and to repeat the stimulus word. The test has a low cognitive and linguistic load by using highly familiar words. Enmarker, Boman and Hygge (1998) state that listening to speech against verbal noise is more demanding than listening against environmental noise, because identical pathways are being used to process both the background speakers and the target speaker. This test aims to reflect the listening conditions of a student in the classroom situation attempting to separate one speaker from multiple background speakers, yet testing individual ear performance under these conditions.

The full *SCAN-C* test is widely used as a screening measure for auditory processing abilities. Its portability, using a cassette player and headphones, has made it a popular tool for situations where attendance at an audiology clinic is not practical. Although the *full SCAN-C* test has been criticised for poor test-retest reliability (r ≤.73) after a 6-7 week interval, these concerns do not apply to the *AFG* component (Amos & Humes, 1998). The validity of the *SCAN-C* test is generally considered acceptable (Amos & Humes, 1998) with a 45% sensitivity rating and a 95% specificity being found (Domitz & Schow, 2000). The full

SCAN-C test score has been found to correlate well with other auditory processing tests, such as the left and right competing components of the *SSW* (r = 0.53 and 0.57 respectively, p<0.001) (Keith, Rudy, Donahue & Katbamna, 1989).

Separation of a single speaker from other speakers (or noise) is the essential element in the process of being able to isolate verbal information prior to entry into short-term auditory memory and subsequent access to meaning. Poor test performance on the *AFG* indicates a difficulty with monaural separation, affecting selective listening and speech discrimination. If the ability to discriminate words in noise is poor, then it could be assumed that this may have an impact on the isolation, retention and storage of language including phonological representations of new vocabulary (and the definitions and associations thereof) in naturalistic environments. Scores on the *full SCAN-C* test have been found to be significantly correlated with the scores on the Peabody Picture Vocabulary Test – Revised (r = 0.39, p<0.03) (Keith et al., 1989). While Cacace and McFarland (1998) questioned whether the *SCAN-C* test was capable of distinguishing auditory processing from vocabulary performance, the correlation could reflect the contribution that clearly discriminated auditory input has upon vocabulary development.

3.4.2.2 Pitch Pattern Sequence- Child (PPS-C) test

The *Pitch Pattern Sequence -Child (PPS-C)* (Pinheiro, 1979) is a monaural test of non-speech frequency discrimination and temporal order judgement. The examinee is required to listen to a sequence of tones (each labelled as either high or low) and then repeat the order of tones presented e.g. high-low-high. A sequence of two tones is used for training and three-tone sequences are used for testing. Each tone has a 500 msec duration presented at 60dBSL. As recommended in the administration guidelines, two plastic blocks of different height were placed on a table directly in front of the participant. The frequency dimension of the different tones were demonstrated manually by the examiner by pointing to the tall block for the 'high' tone (1430Hz) and to the shorter block for the 'low' tone (880Hz). Once this was understood, the participant was then trained to imitate the sequence by humming it until a criterion of ten was achieved for two-tone sequences for each ear and a criterion of five three-tone sequences for each ear. Twenty three-tone sequences were then administered to each ear under headphones, first to the right ear and then the left ear. Results are scored as *PPS-C*:*Right Correct* (*PPS-C[R])* and *PPS-C*:*Left Correct (PPS-C[L]),* representing the correct number of items for each ear expressed as a percentage. For this score any responses that are perfect reversals of the stimulus are not included. A further score that includes perfect reversals is tallied to arrive at a total percentage score: *PPS:Right Total (PPS-C[RT])* and *PPS-C:Left Total (PPS-C[LT]).* These latter totals are collated as Pinheiro (1979) considers reversals to be a problem of output organization of the response and not a deficit of auditory processing of the pitch pattern. The percentages obtained are then compared against normative data. In the absence of means and standard deviations, standard scores were not able to be computed for the *PPS-C.*

Tonal information, including acoustic contours and patterns, is predominantly processed in the right hemisphere (Ross, 1984; Musiek, 1994; Musiek & Lamb, 1994; Kujala, Alho, Valle et al., 2002). Consequently, the auditory pathway for tones presented to the right ear necessitate interhemispheric transfer via the corpus callosum for processing, after subcortical crossing to the left hemisphere. Difficulty with interhemispheric transfer of tonal information plus difficulty with interhemispheric transfer of linguistic information (e.g. on dichotic tests with linguistic load) represent and auditory-linguistic integration deficit (Medwetsky, 2002b).

If auditory pathways, frequency discrimination and temporal ordering are intact, participants would be expected to provide an accurate verbal ‘high’ or ‘low’ in response to the tones. A verbal response requires the non-speech temporal information to be firstly processed predominantly in the right hemisphere and then to cross the corpus callosum for linguistic processing in the left hemisphere. Individuals with learning difficulties have been shown to be able to preserve the sequence of the information in a humming sequence, but not be able to provide accurate verbal sequential responses (Pinheiro, 1979). Medwetsky (2002b) reports similar observations in individuals with APD. As an intact auditory system cannot be assumed in this population an imitative hummed response was requested in preference to a verbal response in order to reduce both cognitive and linguistic processing, especially naming. Nevertheless, a few participants who experienced difficulty providing a hummed response were permitted to provide a verbal response. Usually these participants stated they were ‘too embarrassed’ to hum.

Pinheiro and Musiek (1985b) found that adults with lesions in either the left or right auditory cortex perform poorly on the *PPS-C* but it was not possible from the results to laterally distinguish which hemisphere was affected. Of the seven tests evaluated by Musiek et al.(1982) the *PPS-C* was the most sensitive test to AP difficulties in a population of 8 to 10 year olds (n = 22) with known auditory processing difficulty. The mean scores for the right ear were 41.2% correct and for the left ear 38.4% correct. The subjects obtained the lowest mean score in both ears on the *PPS-C*, corresponding to 72.7% of subjects failing this test, using a verbal response mode. The *PPS-C* was found to have sensitivity of 80% in a later study by Chermak and Musiek (1997) and a specificity of 100% in a study by Domitz and Schow (2000).

The *PPS-C* test was included in this study to explore frequency discrimination and temporal sequencing of non-speech information and therefore the ability to represent pitch patterns. Pitch patterns form part of acoustic contours that are used to interpret stress, duration, rhythm and intonation at the phonologic, linguistic and suprasegmental levels of information processing. If these aspects of auditory processing are weak, it could be assumed that there would be consequences for auditory discrimination of prosody and of speech sounds affecting the representation, storage and processing of new vocabulary, definitions and associations with subsequent effects upon listening, language development and potentially, reading comprehension (Gathercole, Willis, Baddeley & Emslie, 1994). For instance, pitch patterns and intensity patterns combine to form acoustic contours that represent syllabic stress. If the syllabic stress on a multisyllabic word is not accurately processed, the representation of that word may be adversely affected e.g. the weaker syllable ‘com’ may not be well represented in the word ‘computer’ or the representation of ‘diagonal’ may be stored without sufficient information regarding the stronger stress on the middle syllable. Alternatively or in addition, patterns of rhyme may not be recognized across words and the intentions or emotions of a speaker may not be interpreted accurately.

3.4.2.3 Random Gap Detection Test (RGDT)

The *Random Gap Detection Test (RGDT)* (Keith, 2000) is a binaural test of non-speech temporal discrimination. The *RGDT* requires the examinee to state whether two tones are perceived as one tone or two separate tones. Two tones, each of seven-millisecond duration, are presented at 55dBSL, under headphones, with randomly assigned inter-stimulus intervals (ISI) of 0, 2, 5, 10, 15, 20, 25, 30 and 40 milliseconds(ms). The tones are presented in four sets of nine, at 500Hz, 1000Hz, 2000Hz and 4000Hz. The examinee must state whether 'one' tone or 'two' tones were heard, thus the test has a low linguistic load. The shortest time interval, or gap detection threshold, is determined for each test frequency. The gap detection threshold is then averaged across the four test frequencies and expressed as a mean score. The mean score is then compared to the normative data available for the 5 - 11 year age range. An average mean score falls within the range of 2.5 ms to 12.5 ms, but a score of 20msec is deemed to be the upper pass limit of normal performance, based on a review of the literature (Deary, 1995; Keith, 2000).

Keith (2000) views the *RGDT* as a measure of the ability to rapidly process temporal information with minimal linguistic demands from the stimulus or the response. Auditory neurons fire at the onset of a signal while others fire at the cessation of a signal. When the transmission of information is working precisely, tones with an ISI of as little as 2msec are detectable, based on the range obtained in the standardisation sample (Keith, 2000). The assumption to be considered here is that the acoustics of speech have a temporal basis and that an intact auditory system is therefore necessary to detect the smallest changes in the acoustic signal across time, such as the onset of voicing on a phoneme. It has been proposed that temporal gap detection abilities have an impact upon auditory discrimination of speech sounds (Tallal, 1980; Kent, 1997). If that is the case, then it could be assumed that poor temporal gap detection may have an impact on auditory discrimination of words with subsequent ramifications for storage of stable representations of the word, affecting vocabulary development and both listening and reading comprehension. Personal communication with the author of the *RGDT* confirmed that no sensitivity or specificity data have been reported for the *RGDT*.

The inclusion of the latter two tests, the *PPS-C* and the *RGDT*, also attempted to address one common criticism of the clinical auditory processing battery used in the diagnostic process that all the assessments require speech processing (of numbers, words or sentences) and therefore may confound whether a student has linguistic or auditory processing deficits. The *RGDT* requires non-speech input processing and a low level of linguistic demand for a response and the *PPS-C* requires prosodic analysis of non-speech input to be performed and has no linguistic demand for the response.

In summary, the full range of auditory assessments undertaken by all participants either prior to or during the study cover the aspects of auditory performance outlined in Table 4 below.

TABLE 4*:*
Auditory Processing Tests and Corresponding Aspects of Auditory Processing Skill.

Test	**Auditory Processing Skill**
Staggered Spondaic Word Test *(SSW)*	Binaural integration of competing signals
Competing Sentence Test *(CS)*	Binaural separation of competing signals
Digit Span Test *(DS)*	Short-term auditory memory for unsequenced numbers
Sentence Recall subtest *(SR)*	Phonological working memory for meaningful sentences
SCAN-C: Auditory Figure Ground subtest *(AFG)*	Monaural separation of competing signals
Random Gap Detection Test *(RGDT)*	Temporal resolution/gap detection
Pitch Pattern Sequence Test – Child Version *(PPS-C)*	Auditory pattern recognition Frequency discrimination Temporal ordering

As a battery the tests explore whether:

- difficulties with interhemispheric transfer of linguistic information exist
- one speaker can be separated from multi-speaker background noise
- the frequency (pitch) and temporal order (preservation of time sequence) of non-speech sounds are being accurately discriminated and rapidly processed
- sufficient linguistic information is being retained in order for further processing to occur.

3.4.3 Second Assessment Session

The location for the second one-hour session was offered at either Flinders University or a quiet room at the participant's home or school according to their preference. At this session the following measures of language and reading ability were administered:

- the Peabody Picture Vocabulary Test -3 (Dunn & Dunn, 1997);
- the Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs subtest (Semel et al., 1995);
- the Word Attack, Word Identification and supplementary Letter Identification subtests of the Woodcock Reading Mastery Tests-Revised (Woodcock, 1998);
- the Neale Analysis of Reading Ability –3: Form 1 (Neale, 1999).

3.4.3.1 Receptive language assessments

The *Peabody Picture Vocabulary Test-3 (PPVT-3)* (Dunn & Dunn, 1997) is an internationally used and highly respected measure of receptive vocabulary (Katz, Healy & Shankweiler, 1983). Items on the PPVT cover nouns, gerunds (verbs) and descriptors (adjectives and adverbs). Each item is presented as a single word spoken aloud by the examiner to the examinee who then selects the most appropriate referent from four pictures by either pointing to it or saying the number of the picture (1, 2, 3 or 4). Consequently there is minimal expressive language load. The items are arranged in sets of 12. A basal set is established when there is no greater than one error in a set and the ceiling set is established when there are 8 or more errors in a set.

Across 72 studies the *PPVT* has been shown to correlate with the Stanford-Binet Intelligence Scale (SBIS) with a median correlation r = 0.62, and to various versions of the Wechsler Intelligence Scales for Children (WISC) with a median correlation of r = 0.64 (Dunn & Dunn, 1997). The median correlation with the Verbal scale alone on the SBIS is higher at r = 0.69 and on the WISC Verbal scale it is also higher at r = 0.70. Consequently the developers of the *PPVT*, Dunn and Dunn (1997) conclude that the *PPVT* can be considered to correlate moderately well with measures of verbal intelligence. Further, the *PPVT* has been correlated with measures of reading comprehension with a median correlation of r = 0.63.

The *Clinical Evaluation of Language Fundamentals* (*CELF-3)* (Semel et al., 1995) is internationally used as a language evaluation tool in both research and clinical settings and is often considered the gold standard for evaluating the foundations of receptive and expressive language (Keith et al., 1989; Heath et al., 1999; Wake, Poulakis, Hughes, Carey-Sargent & Rickards, 2005). The test-retest reliability of the *total* language score ranges from 0.93-0.94 in the age group of this study. Both the construct and concurrent validity of the *CELF-3* have been well established. For instance, the correlation of the total language score on the *CELF-3* to the Full-scale *and* Verbal scale on the Wechsler Intelligence Scales for Children (*WISC-3)* is .75 (Semel et al., 1995).

The *Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs (CELF-3:LP)* assesses oral language processing of paragraph-length text. Following a demonstration paragraph, two paragraphs are read aloud to the examinee, each followed by 5 questions pertaining to that paragraph. Some questions require the examinee to recall details while other questions require interpretation of the information to deduce inferential, sequential and predictable conclusions. The questions in the *CELF-3*rd revision are coded accordingly in 5 categories for analysis (Main Idea, Detail, Sequence, Inference, Prediction), making this version of the *CELF* desirable for this study. The raw scores are converted to a standard score with a mean of 10 and standard deviation of 3. For the purposes of this study, these standard scores were converted to a mean of 100 with a standard deviation of 15.

The linguistic processing in the *Listening to Paragraphs* subtest engages the processing of meaningful linguistic information by integration of the syntactic and semantic information with the auditory information. Phonological working memory is also an important element, affecting the quantity of information processed. Adequate auditory attention, recall, reasoning and linguistic abilities, including vocabulary knowledge, are required to achieve correct responses. The reported test-retest reliability for the *Listening to Paragraphs* subtest is .61-.7 for the target age group of this study. Each subtest of the *CELF-3* has a mean standard score of 10 with a standard deviation of 3. The mean standard score for a group of children diagnosed with a language disorder (n = 136: aged 6 to 16 years) on the *Listening to Paragraphs* subtest was 7.2 (SD = 3.0) whereas a group of matched non-language disordered children (n = 136: aged 6 to 16 years) achieved a mean standard score of 9.6 (SD = 3.1) indicating the ability of this subtest to discriminate between these groups (Semel et al., 1995). The criterion for language disorder used in this comparison was defined as a Total Language score on the CELF-3 of greater than or equal to one standard deviation below the mean (Semel et al., 1995).

The rationale for inclusion of measures of receptive vocabulary and listening comprehension was two-fold. Firstly, it enables a comparison of auditory processing ability to linguistic ability and secondly it enables a comparison of linguistic ability to reading ability. For instance, an unexpected discrepancy in either direction between listening comprehension and reading comprehension provides valuable information about the possible source of breakdown.

3.4.3.2 Reading assessments

Assessment of reading was achieved by collecting data from standardized tests of single-word reading, non-word reading and text reading in addition to a non-standardized test of alphabetic knowledge and letter-sound correspondence. All reading assessments were audio-taped for later analysis of the reading errors made by the participants.

The *Woodcock Reading Mastery Tests (WRMT)* (Woodcock, 1998) are considered to be the gold standard for reading evaluation, providing solid normative data (Shaywitz, Escobar, Shaywitz, Fletcher & Makuch, 1992). Both current and previous versions of the *WRMT* have been used extensively in reading research (Katz et al., 1981; Katz et al., 1983; Mody et al., 1997; Vellutino et al., 2000). The *WRMT* were used to evaluate two major aspects of the reading process namely, nonword decoding and word recognition via the *Word Attack* and *Word Identification* subtests respectively.

Word attack refers to the ability to decode an unfamiliar word (nonword or real word), using phonological strategies. Nonword reading evaluates access to the phonological code (letter-sound correspondences) without the interference of familiarity with the target word. An important feature of a test of nonword decoding is the minimisation of lexical (whole word) access by analogy to visually similar real words. The majority of the non-words provided in the *WRMT:Word Attack* subtest are not distortions of real English words, reducing, though not eliminating, lexical access via analogy such as ‘glick’ being associated with ‘click’. For this reason the *WRMT:Word Attack* subtest was selected from a range of similar assessments e.g. items commence with consonant-vowel combinations e.g. ‘ap’ and progress to multisyllabic words e.g. ‘bafmotbem’.

The *WRMT:Word Identification* subtest evaluates the reading of real words in isolation which taps the word recognition and/or decoding abilities of the examinee without the assistance of semantics. Goulandris (1996, p. 84) stated that “the best way to assess word recognition is by using a single-word reading test which precludes the use of psycholinguistic, pictorial and contextual cues”. This facility is provided by this subtest, which progresses from high frequency words (e.g. ‘you’) to words which appear with lesser frequency in written English (e.g. ‘furnace’) (Woodcock, 1998).

The scores on the *Word Identification* and *Word Attack* subtests also combine to form a *Basic Skills Cluster* score, using the average of the two scores. The *Basic Skills Cluster* is intended to provide a single measure of word reading ability. The correlation between the results of *Word Attack* subtest and the *Word Identification* subtest is reported as r = 0.70 - 0.79 across Grades 1-5 (Aguiar & Brady, 1991; Woodcock, 1998).

Correlations between the *WRMT* with other measures of reading ability including the Iowa Tests of Basic Skills and the Wide Range Achievement Test *(WRAT)* have been found to be in the range of r = 0.78-0.88 (Woodcock, 1998). A particular advantage of the *WRMT* is the ability to directly compare results on the decoding and identification measures of reading ability based on the same normative population and data.

In addition, the *Supplementary Letter Checklist* subtest of the *WRMT* was administered as a measure of letter naming and letter-sound correspondence. Participants were asked to provide the letter name for all letters of the alphabet, presented out of alphabetical sequence and then to provide the sounds corresponding to those letters, again presented out of alphabetical sequence. A 1:1 score for letter naming and separately for sound-letter correspondence was tallied, but not norm-referenced, as this was not available. Letter naming and sound-letter correspondence in the first year of schooling are considered to be strong predictors of later reading attainment (Goulandris, 1996), reflecting a combination of phonological awareness and phonological working memory.

The *Neale Analysis of Reading Ability – 3 (NARA-3)* (Neale, 1999) is an assessment of text reading, provided as 2 concurrent forms (Forms 1 & 2). Form 1 was used in this study. Text reading engages not only linguistic processing to the reading task, but also a range of cognitive processes including association, inferencing, interpretation, self-monitoring and prediction. The *NARA-3* was developed in Australia and each form contains 6 passages that have been carefully graded by selecting the subject matter, vocabulary, complexity of the syntax and the overall length of each passage across the six levels. The examinee is timed while reading the passage aloud and is then asked a set of comprehension questions pertaining to that text. The first test paragraph has four comprehension questions and subsequent paragraph have eight comprehension questions each.

Text reading on the *NARA-3* is analysed in terms of *Reading Accuracy, Reading Comprehension* and *Reading Rate*. The total score achievable on the *NARA-3: Reading Accuracy (RA)* component is 100 points. Sixteen points are awarded for each of the first five passages containing no errors (maximum 80 points). The level 6 paragraph is awarded 20 points with no errors. Each error is transcribed and counts as 1 point to be deducted from the passage total.

A simple error categorisation procedure is provided in the *NARA-3* for analysis of accuracy. Reading errors can be tallied under 6 categories: mispronounciations, substitutions, refusals, additions, omissions and reversals.

Error percentages can be calculated, but the probability of occurrence of an error type is not known. Self-corrections to the target word are considered correct and the original error is not categorised. Recasts, whereby the reader re-reads from the beginning of the sentence or phrase, are not recorded.

This study is concerned with the evidence provided by reading errors in relation to the reading strategies being used by the participant and their ability to shift between strategies while reading. Accordingly, an error schema and guidelines for text reading were created for this research, hereon referred to as the *Reading Accuracy Profile* or *RAP* (see Appendix I). For the purposes of this study an error has occurred when the target word is not read correctly or is not read at all. The reader may then use strategies to arrive at the target, with variable success. The *RAP* analysis aims to capture all of the information from the initial error as well as the strategies utilized. As recasts and self-corrections provide valuable information about the reader's ability to self-monitor errors and utilize different decoding strategies it was important to include this information in the analysis. The guidelines provide the notation system for recording errors (see Appendix J). The schema takes the form of an expanded attribution system similar to that used in the *NARA-3*, however the 6 categories provided in the *NARA-3* were expanded to 15 sub-categories assembled under 7 category headings.

Rater reliability on the *RAP* analysis was checked by an independent educator trained in reading remediation. Initial cross-checks on five analyses led to a rater reliability figure of 50%, largely due to confusion regarding two error substitution categories (meaning vs. word shape influence). Following resolution of contentious error categorisations, with accompanying clarification in the guidelines, rater reliability was re-checked and attained a reliability figure of 78 %

on two analyses. Further clarifications were then added to the guidelines to address the remaining confusions.

Reading accuracy scores derived from text reading are considered to be a measure of contextualized word reading. On the *RAP* analysis each error was assigned as either ‘Meaning Lost’ or ‘Meaning Retained’. This was determined by whether the error affected the *intended* meaning of the text. For instance, an error such as ‘alighting on the back of sheep’ instead of ‘alighting on the *backs* of sheep’ does not affect the author’s meaning whereas ‘they had found a place’ rather than ‘they had found a *palace’* does affect intended meaning. It is noteworthy that sometimes substitutions of ‘a’ for ‘the’ or vice-versa did affect meaning while at other times they did not. There was no judgement made of whether the participant’s understanding was affected, only whether or not the error changed the meaning of the sentence. ‘Meaning lost’ vs. ‘meaning retained’ data were calculated as a percentage for each participant based upon the number of ‘meaning lost’ or ‘meaning retained’ errors as a percentage of the total errors made for that participant. Conversion to percentages removes any concern about the probability of occurrence of error types that would or would not affect meaning when comparing data across groups.

The 15 error sub-categories were as follows:

1. Loses Place- visual: This error was identified at the moment of occurrence when the reader skipped an entire line or otherwise indicated that they had lost their place on the line.
2. Recast – meaning: This error was identified when the reader re-read a word or phrase i.e. error was not reading the next word. Any errors contained in the initial reading or the recast are coded separately.
3. Deletion – whole word: This error was recorded when a whole word was deleted from the text.
4. Addition – whole word: This error was recorded when a whole word was added to the text.
5. Letter reversal – visual: This error was recorded when one letter within the word has been reversed either horizontally or vertically e.g. bad/dad, wet/met.
6. Word reversal: This error was recorded when two or more letters were reversed within the word e.g. on/no, of/for, was/saw
7. Substitution – first sound/letter influence: This error was recorded when the first letter, digraph, sound or consonant blend in the error matched the target word and the error was a real word e.g. date/dead, his/her, black/blue. It is reasonable to assume that semantics may often influence this error, but no judgement was made.
8. Substitution – first syllable/s influence: This error was recorded when at least the onset and the first vowel of the error matched the onset and first vowel of the target word and the error was a real word e.g. offence/offside, searching/searched, track/traffic, telephone/television.

Once again, semantics may have influenced the error but no judgement was made.

9. Substitution – word shape influence: This error was recorded when it is judged that the visual shape of the *whole* word has influenced the error and the error is a real word e.g. purpose/porpoise, safely/safety, where/were.
10. Substitution – meaning influence: This error was recorded when the error makes sense but bore no visual similarity to the target word e.g. pond/river, a/the.
11. Substitution – no relationship: this error was recorded when there was no clear relationship between the error and the target, but the error was a real word e.g. her/was, face/traffic.
12. Mispronunciation/decoding error: this error was recorded when the reader attempted to decode the word using sounding, but did not achieve the correct pronunciation e.g. instayntly/instantly, spak/space. Usually the resultant error was not a real word. Occasionally the word may be blended incorrectly, but sound like a real word e.g. p-ah-t → ‘parrot’ for ‘part’. If it was clear that grapheme –phoneme conversion was being utilized the error was placed here rather than as a substitution. With the exception of proper nouns, meaning of the text at that point was assumed to have been lost for all mispronunciations.
13. Deletion – part word or morpheme: This error was recorded when part of the word, frequently a morpheme, was omitted e.g. smile/smiles or a contraction occurs e.g. can’t/cannot. The base word had to be the same for both the target and the error e.g. a/an.

14. Addition – part word or morpheme: This reversal was the opposite form of the above error whereby part of the word or a morpheme was added e.g. smiles/smile, burrowing/burrow. Again, the base word had to be the same e.g. into/to.
15. Other : All other errors were recorded as ‘Other’. This included refusal to attempt a word, unintelligible words, articulation errors and non-standard English pronunciations e.g. ‘ekscape’ for ‘escape’; ‘aksed’ for ‘asked’. Articulation errors and non-standard pronunciations were deemed to retain meaning while refusals and unintelligible responses were considered to have lost meaning.

All attempts at a word were transcribed individually on the *RAP*, including multiple attempts at one word, regardless of whether the word was subsequently self-corrected. The total number of successful self-corrections was also tallied. All error tallies for each error type were converted to a percentage of the total errors made for that participant. The above coding of error types on the *RAP* enables a descriptive analysis of reading errors and is intended to shed some light upon the distribution of phonologically, semantically or visually based errors. To this end, the 15 error sub-categories were assembled under 7 category headings as follows:

1. Visual

- loses place (error 1)
- letter reversal (error 5)
- word reversal (error 6)

2. Recast-meaning (error 2)

3. Deletions

- whole word deletion (error 3)
- part word deletion (error 13)

4. Additions

- whole word addition (error 4)
- part word addition (error 14)

5. Substitutions

- first sound influence (error 7)
- first syllable/s influence (error 8)
- word shape influence (error 9)
- meaning influence (error 10)
- no relationship (error 11)

6. Decoding (error 12)
7. Other (error 15)

Even though the sub-categories are assembled into the 7 super-categories above for simplification, the descriptive analysis will highlight interesting findings in relation to both super-categories and sub-categories.

The score for the *NARA-3: Reading Comprehension (RC)* component is the number of comprehension questions correct to a maximum of 44 points. The questions test recall of details, understanding the main idea, recalling the sequence of events and inferencing. Correct responses can be classified accordingly should this analysis be explored. However, only two questions typed provided a sufficient number of responses for analysis: recall of details and inferencing.

When reading accuracy is poor, fewer passages may be read overall, reducing the opportunity to respond to the reading comprehension questions for unread passages, potentially resulting in a false poorer reading comprehension score. Nation and Snowling (1998b) tested this assertion by checking the scores of the participants in their control group (n = 16) and their poor comprehender group (n = 16) who had read *all* paragraphs and found that the poor comprehenders still had significantly lower RC ability. It was not considered necessary to repeat this procedure for this study. Unlike, the Nation and Snowling study, this study wishes to investigate less-skilled readers who may be poor decoders as well as poor comprehenders.

The score on the *NARA-3*: *Reading Rate (RR)* component is a calculation of the number of words read divided by the time taken to read, multiplied by 60 (seconds) and expressed as words per minute.

Versions of the *NARA* have been used in international reading research (Yule, 1973; Rutter & Yule, 1975; Bradley & Bryant, 1983; Waring et al., 1996; Prior, Sanson, Smart & Oberklaid, 2000). Test-retest reliability co-efficients for the three components of the *NARA-3* range from .93-.95 (Neale, 1999). Measures of construct and concurrent validity are also strong. Performance on the *NARA-3* can differentiate age and therefore reflects a developmental skill. Neale (1999) reports the components of the *NARA-3* correlate with other tests of reading such as the Schonell Reading Test within the range of r = 0.76-0.96. Correlations between the *Reading Accuracy* and *Reading Comprehension* components with the Vocabulary subtest on the *WISC-R* range from r = 0.58-0.68. The 1999 standardisation procedure for the *NARA-3* included 1394 children, from Year 1 to

Year 7 across Australian schools (Neale, 1999). The availability of Australian normative data also made the *NARA-3* a desirable choice for this study.

3.5 Severity Measures

Three severity measures of auditory processing deficits were derived in preparation for analysis of correlations to the language and reading results. The three measures were firstly, an auditory processing severity score (APS) based upon the total FUSAPB (*SSW*, *CS*, *DS* and *SR*) and secondly, an auditory processing – dichotic listening severity score (AP-DL) based upon the two dichotic tests in the test battery (*SSW* and *CS*) and thirdly, an auditory processing – short-term memory severity score (AP-STM) based upon the two short-term memory tests in the test battery (*DS* and *SR*). In each case the standard scores on all tests were added and then divided by the number of tests. The three severity scores allow correlations with the full AP battery that was used to determine APD diagnosis, but also the dichotic listening and STM components separately. These three measures were used to determine whether *severity* of AP difficulty adversely affected language and reading performance.

CHAPTER FOUR

Method

4.0 Study Two

4.1 Recruitment Process

A control group of students with average reading ability was sought in order to achieve reading-age matched participants for the APD group. The participants for Study Two were not accessed from a database as they had not undergone previous AP testing. Consequently, schools were approached, seeking their willingness to participate and assist with identification of potential participants with average reading ability.

Ethical approval was granted by the Queensland Government Department of Education and the Arts and by Catholic Education, Archdiocese of Brisbane (see Appendices K & L). In total, 26 State schools and 4 Catholic schools were invited to take part in the research. Of these, 10 State schools and 2 Catholic schools agreed to participate (see Appendix M). An invitation to participate in the research was sent to the principals of Queensland schools deemed to cover a range of socio-economic status groupings (see Appendix N). Each principal was asked to complete and return an expression of interest (see Appendix O). Following receipt of the expression of interest, the principal was contacted and if there was agreement to proceed, a principal’s consent form and information kits were forwarded for distribution to relevant class teachers with a covering letter (see Appendices P & Q). Class teachers were asked to identify students in their class who they deemed to be of average reading ability, using available National

Assessment Program Literacy and Numeracy (NAPLAN) benchmark data (Ministerial Council on Education Employment Training and Youth Affairs) and any other available formal results of reading ability to guide selection. Class teachers were then asked to provide the invitation, the parent questionnaire and consent form to prospective families as per Study One. Once the parent information was returned, it was placed together with the class teacher consent form and student identification sheet (see Appendices R & S) and returned to the researcher.

The inclusion criteria were identical to the inclusion criteria for the APD and NAPD groups with the addition of the following criteria:

- no history of or current speech or language difficulty;
- no history of or current reading difficulty;
- no history of or current learning support;
- reading ability within the average range;
- sentence recall ability on the Sentence Length test within the average range (Rowe et al., 2004).

The first four inclusion criteria above were stated in the invitation to participate and were substantiated via the parent questionnaire previously described. To assist matching of socio-economic status (SES) between the APD group and the Average group, a question was added to the questionnaire for Study Two regarding the highest level of educational attainment for the natural mother and natural father. See forthcoming section 4.2.2 on the determination of SES for validation of this process.

4.2 Participants

Initially, thirty-eight *potentially* Average readers (24 males and 14 females) were recruited, aged between 7 years 5 months and 12 years 1 month. The participants were drawn from 10 Queensland State schools and 2 Catholic Education schools in the Brisbane metropolitan and Sunshine Coast regions. Ultimately, 21 Average readers (aged 7;5 to 10;5) were matched for reading age to 21 APD readers (aged 8;3 to 11;0) for Study Two.

In order to determine average reading status for the reading-age matched participants the raw scores on the *NARA-3* were converted to standard scores with a mean of 100 and standard deviation of 15 in order to compare participants to the normal distribution. Average reading ability was defined as being within one standard deviation of the mean standard score of the *NARA-3: Reading Accuracy* component, representing the score range expected for the middle 68.26% of the population and corresponding to stanines 4-7. Standard scores, percentile ranks or reading age equivalencies are frequently used in research to determine average reading status (Snowling et al., 1986; Gillon & Dodd, 1993; Fawcett, Nicolson & Dean, 1996; Hultquist, 1997; Manis et al., 1997; Bruno et al., 2007). Standard scores within one standard deviation of the expected mean and equal to or greater than the expected mean have been used to determine average reader status (Katz et al., 1981; Hultquist, 1997). Percentile ranks equal to or greater than 40 or equal to or greater than 50 have been used in different studies (Manis et al., 1997; Bruno et al., 2007). Reading age equivalency criteria varying from within 12 months of chronological age to equal to or greater than chronological age have also been used (Snowling et al., 1986; Gillon & Dodd, 1993; Fawcett et al., 1996; Hultquist, 1997). Standard scores were deemed more suitable for this study as the range of age equivalencies of average reading differs according to age bands. For instance, the average range spans 23 months in the Year 3 norms in the *NARA-3*, but spans 54 months (a range of 4 ½ years) in the Year 4 norms. That is, it is considered within the average range for a Year 4 student to obtain an age equivalency far exceeding chronological age. Again as a consequence of this breadth of age equivalencies, standard scores were deemed more appropriate for this study.

As an interesting note, four potential participants, identified as average readers by their class teacher, were in fact reading well above average and were therefore, excluded. A further two individuals were excluded: one due to the failure to pass the screen of hearing acuity and the other due to a below average score on the Sentence Length test.

4.2.1 Matched APD and Average Reader Participants

Matching for reading age allowed investigation of any differences in standard scores for language ability, word attack, word recognition, reading accuracy, reading comprehension, reading rate and reading error patterns between the APD and Average readers that cannot be attributed to lack of reading experience. Twenty-one Average reader participants were matched to twenty-one participants from the APD group (from Study One) for reading age, gender and socio-economic status.

Of the reading measures used in this study, single word reading and reading accuracy were the most common measures used for matching purposes in a sample of studies reviewed (Katz et al., 1981; Snowling et al., 1986; Gillon &

Dodd, 1993; Fawcett et al., 1996; Hultquist, 1997; Swan & Goswami, 1997a). Twenty-one Average reader participants were able to be matched to participants in the APD group for the *NARA-3: Reading Accuracy* subtest. All participants read between 2-6 passages on the *NARA-3*, corresponding to a possible score range of 32-100 points without errors or 0-100 with errors. The matching process was achieved by firstly, seeking the closest raw score matches, which was achieved to within 7 points. This resulted in a reading age equivalency match to within 9 months for each pair. As average reader status is considered to be within 12 months either side of chronological age i.e. a range of 24 months, a match of up to 9 months apart was considered an acceptable range of difference. Previous reading-age matched studies have used differences of 7 months apart in the 8- 12 year old age group (Swan & Goswami, 1997a) and 10 months apart in the 10-13 year old age group (Rack, 1985).

Twenty one Average reader participants were also able to be matched to participants in the APD group on the *WRMT: Word Identification* subtest to within 7 raw score points, corresponding to an age equivalency match to within 8 months. Nineteen pairs were identical across both the *NARA-3: Reading Accuracy* component matching process and the *WRMT:Word Identification* subtest matching process. Word identification ability and (text) reading accuracy scores do not always match as comprehension processes will interact with reading accuracy in the text reading task, raising or lowering the reading accuracy predicted from word identification (Nation & Snowling, 1998b). While word recognition (single word reading) is particularly relevant in dyslexia research it was determined that connected reading ability was more pertinent to the current research investigating the interaction of auditory processing, language and reading abilities. In particular, the effect of phonological working memory, the progressive retrieval of phonological representations and the progressive retrieval of semantic representations and the subsequent effect on reading comprehension are under scrutiny here. The *NARA-3:Reading Accuracy* component also afforded use of Australian normative data and as a further important rationale, the *RAP* error analysis was performed on the *text* reading results. A comparison of error differences in text reading is more meaningful where the participants have been matched on the same measure. Consequently, it was decided to use the set of twenty-one pairs matched on the *NARA-3:Reading Accuracy* component as the reading-age matched groups.

The socio-economic status (SES) match (see forthcoming section) was achieved to within one adjacent category of the five categories for educational attainment for both parents in 12 cases, for one parent in 6 cases and was unknown for 3 cases. Gender matching was achieved with one exception. A summary of the age and gender distribution of the matched APD and Average groups is detailed in Table 5 below.

TABLE 5*:*
Matched APD and Average Reader Participants by Group for Study Two

APD group (n=21)		**Average reader group (n=21)**		**Total (n=42)**	
Male	Female	Male	Female	Male	Female
13	8	14	7	27	15
Age range: 8;3- 11;0		Age range: 7;5-10;5		Age range: 7;5-11;0	

Chronological age between the matched groups was compared in order to meaningfully compare language and reading performance. The chronological age of the matched groups (APD group mean age = 9;5 , SD = 7.3 months compared to the Average group mean age = 8;4, SD = 10.9 months) *was* significantly different, using the Wilcoxon Signed Rank test for matched pairs (z = -3.55, p<0.01). Performance on the *Raven's Coloured Progressive Matrices* (APD group mean = 100, SD=10.5 compared to the Average group mean = 110, SD= 11.4) was also significantly different (z = -2.42, p=0.02) though both mean scores fell solidly in the average range, as displayed in Table 6. There was no significant difference in the gender composition (X^2 [df =1] = 0.104, p> 0.05, ns) between the two groups.

TABLE 6:
Comparison of RCPM Scores for Matched APD and Average Reader Participants.

APD group (n=21)		**Average reader group (n=21)**		**Total (n=42)**	
Mean	SD	Mean	SD	Wilcoxon Signed Rank test	Sig level
100.38	10.53	110.24	11.41	-2.42	0.02
Range: 90 to 119		Range: 90 to 125		Range: 90 to125	

The validity of the reading –age match between the two groups was confirmed on the basis of a non-significant difference between the raw scores (APD group mean = 42.81, SD = 15.67 compared to the Average group mean = 44.76, SD = 16.43, z = -1.93, p=0.05, ns) or age equivalency data (APD group mean = 8;4, SD = 19.58 months compared to the Average group mean = 8;5, SD = 20.07 months: z = -1.55, p = 0.12, ns) on the *NARA-3: Reading Accuracy* component.

Chi-square analysis showed a significantly higher number of participants in the APD group had a history of speech and/or language support (X^2 [df=1] = 28.09, p<0.001), current speech and/or language concerns (X^2[df=1]= 18.17, p<0.001), history of reading support (X^2 [df=1] = 31.14, p<0.001), current reading support (X2[df=1] = 16.04, p<0.001) and family history of learning difficulty (X^2[df=1] = 4.677, p=0.03) than the Average group. A significantly higher number of participants in the APD group had a diagnosis of ADHD (X^2[df=2] = 7.61, p=0.02) and associated current medication (X2[df=2] = 6.75, p=0.03) than in the Average group. In real terms, there were 4 participants who had been diagnosed with ADHD in the APD group and 0 participants in the Average group.

4.2.2 Determination of Socio-economic Status (SES)

The Australian Bureau of Statistics (ABS) uses a multivariate technique known as principal component analysis to determine the socio-economic status of people across different geographical areas, using data from the Census Collection District (CD). The outcome is described in the form of indices which are derived from the census information about income, educational attainment, occupation and types of accommodation. Of these measures, parental educational qualifications contribute the greatest weighting to the SES index attributed to that geographical area (Adhikari, 2006). Relevant variables that were used by the ABS to calculate the Indices of Relative Socio-economic Advantage/Disadvantage (IRSA/IRSD) and the Index of Education and Occupation from 2001 Census data include percentages of persons over 15 years of age who:

- left school at Year 10 or earlier (used in the IRSD);
- left school at Year 11 or earlier (used in the IRSA);
- have no further qualification;
- have an advanced diploma or diploma qualification;
- have a degree or higher.

In order to control for the effects of differences in socio-economic status (SES) it was necessary to determine a method of matching the socio-economic status of the APD group to the Average group. For this reason, information about parental educational attainment was obtained for both the South Australian and Queensland participants to assist SES matching[7]. A follow-up letter was sent to the families of Study One participants seeking information pertaining to educational attainment of both parents as this was not originally included in the questionnaire.

---

[7] While direct communication with the author of the Socio-Economic Indexes for Areas, Pramod Adhikari, cautioned against the translation of geographical information to individuals, there is presently no superior process and the Australian Bureau of Statistics is currently investigating whether the same methodology used for geographical areas is indeed valid for individuals, though it may be some time before this information is publicly available.

The educational information was classified into five groupings based on level of education attained:

Group 1. less than Year 10;
Group 2. Year 10 or 11;
Group 3. Year 12; no further qualification;
Group 4. Diploma or trade certificate;
Group 5. Degree or higher.

Tables 7 and 8 display the SES distribution of the matched participants based on parental educational attainment.

TABLE 7:
SES Distribution of Matched APD† and Average Reader Participants by Group, based on Paternal Educational Attainment.

Group 1: < Year 10		Group 2: Year 10 or 11		Group 3: Year 12		Group 4: Diploma or trade certificate		Group 5: Degree or higher	
APD	Average	APD	Average	APD	Average	APD	Average	APD	Average
1	0	5	4	4	4	4	8	4	5

†Educational attainment information was unable to be collected from 3 APD participants

TABLE 8:
SES Distribution of Matched APD† and Average Reader Participants by Group, based on Maternal Educational Attainment.

Group 1: < Year 10		Group 2: Year 10 or 11		Group 3: Year 12		Group 4: Diploma or trade certificate		Group 5: Degree or higher	
APD	Average	APD	Average	APD	Average	APD	Average	APD	Average
3	0	5	4	1	3	3	7	6	7

†Educational attainment information was unable to be collected from 3 APD participants

The validity of the matched groups was further confirmed by a non significant difference between the paternal educational status (X^2 (r) = 3.297, p=0.654, ns) or the maternal educational status (X^2 (r) = 5.469, p=0.361, ns) of the APD group and the Average group.

4.3 Data Collection Procedure and Materials

In Study Two an appointment with each participant was arranged in a quiet room at their school. At the appointment the following tests were administered:

- a screen of hearing acuity at selected frequencies described below;
- the Raven's Coloured Progressive Matrices (Raven et al., 1995) as a measure of non-verbal intellectual ability;

- the Sentence Length test (Rowe et al., 2004) as a measure of auditory processing ability;
- the Peabody Picture Vocabulary Test -3 (Dunn & Dunn, 1997);
- the Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs subtest (Semel et al., 1995);
- the Word Attack, Word Identification and supplementary Letter Identification subtests of the Woodcock Reading Mastery Tests-Revised (Woodcock, 1998);
- the Neale Analysis of Reading Ability –3 (Neale, 1999).

Administration of the screen of hearing acuity, the RCPM, language and reading tests was identical to Study One, with the exception that the screen of hearing was performed using a portable audiometer in a quiet, but not sound-proof, room. Consequently the pass criterion for each of the four frequencies (500Hz, 1kHz, 2kHz, 4kHz) was raised to 25dBHz. The Average reader group did not undergo the FUSAPB and instead the *Sentence Length (SL)* test (Rowe et al., 2004) was included as a measure to indicate auditory processing ability. The *SL* test is a test of sentence recall that was designed as part of the Auditory Processing Assessment Kit (Rowe et al., 2004) . The kit is specifically designed as a screening tool to identify children who may be at risk of an auditory processing disorder. The *SL* test was chosen from a range of sentence recall tests available because it was developed in Australia by a team of researchers which included an audiologist and paediatrician and provided recent Australian norms. The normative data for the *Sentence Recall (SR)* test used in the AP battery were derived from performance data of 175 students in a sound-proof setting whereas the *Sentence Length (SL)* normative data were derived from the performance of 10,126 students in the naturalistic school setting, making this a more valid measure for this phase of the study. No sensitivity or specificity data is known at present. Participants had to pass the screen of hearing acuity and attain an average result (or higher) on the *SL* test for inclusion in the study.

The other oral language and reading tests have been previously described in Study One. All reading tests were again audiotaped for transcription and *RAP* analysis of errors.

4.4 Summary of Method

The research design of Study One allows differences in receptive vocabulary, listening comprehension, word identification, word attack skills, reading accuracy, reading comprehension and reading rate between the APD group and NAPD group to be compared to test Hypothesis 1. Study One also allows the effect of the degree of the auditory processing deficits upon oral language skills and reading ability to be explored to test Hypothesis 2. Inter-correlations between PWM, the receptive language tests and reading tests can be performed to test Hypothesis 3. The *RAP* analysis of error types enables a descriptive analysis of the differences in reading accuracy breakdown between the APD and NAPD groups to test Hypothesis 4.

The design of Study Two allows differences in receptive vocabulary, listening comprehension, word identification, word attack skills, reading accuracy, reading comprehension and reading rate between the APD group and Average reading-age matched group to be compared to test Hypothesis 5. Again, inter-correlations between PWM, the receptive language tests and reading tests can be performed to test Hypothesis 6. The coding and percentages of errors that were

'Meaning Lost' or 'Meaning Retained' allowed descriptive and quantitative comparison between the reading errors of APD readers and Average readers. The *RAP* analysis of error types enables a descriptive analysis of the differences in reading accuracy breakdown between the matched APD and Average reader groups to test Hypothesis 7. The two studies are summarized in Table 9.

Statistical analysis was performed using the SPSS® version 15.0 statistical software system. All participating families received an individual summary of their child's performance.

TABLE 9:
A Summary of the Purposes of Study One and Study Two.

STUDY	**Group 1**	**Group 2**	**Purposes**
Study One	APD (n=28)	NAPD (n=20)	Comparison of auditory processing, receptive language and reading ability. Analysis of the relationship between APD severity and language and reading performance. Analysis of the relationship between auditory processing, receptive language and reading ability. Descriptive comparison of reading error patterns.
Study Two (2 reading-age matched groups)	APD (n=21)	Average (n=21)	Comparison of receptive language and reading ability. Descriptive comparison of reading error patterns.

CHAPTER FIVE

Results

5.0 Study One

As reported in the Method, there was no significant difference in the chronological age, gender composition or performance on the RCPM measure of non-verbal intellectual ability between the APD and NAPD groups.

The analysis for Study One firstly compared the phonological working memory, receptive language and reading abilities of the APD group (n = 28) to the NAPD group (n = 20) using the Mann-Whitney U-test, a non-parametric test for independent samples. Then, using Spearman's Rank Order correlations, the relationship between the degree of AP deficits (severity measures) and both the receptive language and reading scores was analysed for the APD group and the combined APD+NAPD group. Correlations between the auditory processing results, language and reading results were also performed for each group. Discriminant analysis was performed to determine the most discriminating variables for APD vs. NAPD group membership. Regression analysis was performed to determine the strength of contributing independent variables to reading accuracy and reading comprehension. The independent variables selected from the literature were the standard scores for non-verbal intellectual ability (*RCPM*), phonological working memory (*SR)*, vocabulary (*PPVT-3*), listening comprehension (*CELF:LP*) and the word identification and word attack subtests of the *WRMT (WRMT:WI* and *WRMT:WA).* The standard scores on the *SSW(LC)* were added to the regression variables due to the outcome of the discriminant analysis. Finally, a descriptive analysis of the reading error patterns for the two groups was performed.

Standard scores were selected for the statistical analyses because the tests of phonological working memory, vocabulary and reading do not demand completion of a fixed set of items, but are discontinued once a ceiling is reached. Consequently, raw score analysis would be invalid across participants, where one may have read more paragraphs than another giving greater opportunity for a higher score. Therefore, for the purposes of this study, standard scores were calculated for all auditory tests to allow comparisons both within the FUSAPB (Flinders University standard auditory processing battery) and with the language and reading tests.

5.1 Auditory Tests

As hypothesized and previously reported in Table 2 in the Method section the performance on the auditory processing tests (*Staggered Spondaic Word Test, Competing Sentences test*, *Digit Span test*, *Sentence Recall subtest*) in the FUSAPB was significantly lower ($p \leq 0.01$) for the APD group compared to the NAPD group, with the exception of the *Digit Span (DS)* test ($z = 0.17$, $p=0.86$). This was the expected result, with the exception of the findings for the *DS* test. Mean standard scores on the *DS* test for both groups were below one standard deviation from the expected mean. Therefore, the result indicates that the NAPD group (as a whole) is experiencing short term auditory memory and/or auditory attention difficulties to a similar degree as the APD group.

The findings are consistent with interhemispheric transfer deficits as demonstrated by significantly poorer performance on the *SSW(LC)* and *CS(W)* tests.

However, significantly poorer performance on the *SSW(RC)* and *CS(S)* tests also indicate possible auditory discrimination, linguistic and attention deficits also. Performance on the *Sentence Recall (SR)* measure of PWM was significantly poorer for the APD group on both the *SR(B)* scores ($z = -2.67$, $p<0.05$) and the *SR(C)* scores ($z = -2.62$, $p<0.05$). The APD group exhibited significantly poorer phonological working memory (PWM) compared to the NAPD group.

Spearman's correlations between assessed AP skills were performed to explore possible relationships between discrete auditory skills and PWM performance on the *DS*, *SR(B)* and/or *SR(C).* There were no significant correlations between any of the individual dichotic listening tasks and either short-term memory or PWM. Instead, the scores on the non-competing conditions of the *SSW* test had moderate correlations with the *SR(B) & (C)* tests, as shown in Table 9. This result is suggestive of underspecified phonological representations affecting rapid perception and/or weaknesses in phonetic encoding for the items in the non-competing condition.

5.1.1 Extension Auditory Tests

There was no significant difference between performance on the *AFG*, *PPS-C* or *RGDT* tests between the APD and NAPD groups, as shown in Table 10. Performance on the *AFG* was within the average range for both groups. Performance on the *PPS-C* was measured as a percentage correct and deemed to be within the expected range according to the scoring guidelines. In the absence of data pertaining to means and standard deviations, standard scores were not computed. However, performance on the *RGDT* was well below the average range for both groups. The mean standard score for the APD group was 36, representing a mean ISI of 21.96

milliseconds compared to a mean standard score for the NAPD group of 48, representing a mean ISI of 18.22 milliseconds. Interestingly, this may correspond with the reported upper limit of 20 milliseconds for normal performance (Deary, 1995; Keith, 2000).

TABLE 10:
Mean scores on extension AP testing compared by group[a].

Test	APD group (n=28) mean (SD)	NAPD group (n=20) mean (SD)	Mann-Whitney U Test	Sig. level (p≤ 0.05, 2-tailed)
SCAN-C: Auditory Figure Ground	89.04 (10.07)	90.80 (10.47)	-0.52	p=0.60 NS
Pitch Pattern Sequence Test–Child: Right Ear	83.21 (19.21)	82.50 (19.79)	-0.32	p=0.97 NS
Pitch Pattern Sequence Test-Child: Left Ear	81.61 (22.49)	81.75 (20.58)	-0.17	p=0.86 NS
Pitch Pattern Sequence Test-Child-Right Total	90.54 (10.03)	91.0 (14.83)	-0.93	p=0.35 NS
Pitch Pattern Sequence Test-Child: Left Total	88.04 (15.83)	91.0 (12.31)	-0.57	p=0.57 NS
Random Gap Detection Test	36.30 (73.41)	48.12 (71.58)	-0.43	p=0.67 NS

a Test comparisons are based on standard scores with the exception of the Pitch Pattern Sequence Tests which are based on percentage correct.

Relationships between the non-speech auditory skills and PWM performance on the *DS*, *SR(B)* and/or *SR(C)* were also explored. Analysis showed significant Spearman's correlations between one of the non-speech tests, the *Random Gap Detection Test* with the *Digit Span* test for the APD group only. The other non-speech test, the *Pitch Pattern Sequence test (PPS-C[R] & PPS-C[RT])* had a moderate-strong correlation with the *SR*(*B) test* and the *PPS-C(RT)* had a moderate correlation with the *SR(C*) test. Tentatively, these results suggest a relationship between frequency discrimination abilities and phonological working memory. The correlations are shown in Table 11.

TABLE 11:

Spearman's Correlations between Tests of Auditory Short-Term Memory, Phonological Working Memory and other Auditory Processing Measures for the APD Group (n=28)

Test	DS	SR (B)	SR(C)
SSW(RNC)	0.24, p=0.21 NS	0.64, p<0.01**	0.39, p=0.04*
SSW(LNC)	0.39, p=0.04*	0.22, p=0.25 NS	0.40, p=0.03*
SSW(RC)	0.27, p=0.86 NS	0.35, p=0.07 NS	0.21, p=0.28 NS
SSW(LC)	0.07, p=0.73 NS	0.28, p=0.16 NS	0.14, p=0.48 NS
CS(S)	0.00, p=0.10 NS	0.09, p=0.64 NS	-0.09, p=0.65 NS
CS(W)	-0.09, p=0.66 NS	-0.15, p=0.46 NS	-0.22, p=0.27 NS
AFG	0.04, p=0.85 NS	0.37, p=0.05 NS	0.04, p=0.84 NS
PPS-C(L)	0.31, p=0.12 NS	0.38, p=0.05*	0.11, p=0.50 NS
PPS-C(LT)	0.26, p=0.19 NS	0.28, p=0.15 NS	0.12, p=0.53 NS
PPS-C(R)	0.31, p=0.11 NS	0.47, p=0.01*	0.33, p=0.09 NS
PPS-C(RT)	0.20, p=0.30 NS	0.54, p<0.01**	0.40, p=0.04*
RGDT	0.46, p=0.02*	0.08, p=0.71 NS	0.11, p=0.57 NS

*significant at 0.05 ** significant at 0.01

KEY: DS = Digit Span test; SR = Sentence Recall test : (B) = Basal, (C) = Ceiling; SSW = Staggered Spondaic Word test; (RNC) = Right Non-competing condition, (LNC) = Left non-competing condition, (RC) = Right competing condition, (LC) = Left competing condition; CS = Competing Sentences test: (S) Strong, (W) Weak; AFG = Auditory Figure Ground test; PPS-C = Pitch Pattern Perception test – non-speech test, (L) = LeftEar, (R) = Right Ear, (LT) = Left Total, (RT) = Right Total; RGDT = Random Gap Detection Test – non-speech test

5.2 Group Comparison on Language Measures

The scores on the receptive language tests (*PPVT-3* & *CELF:LP*) were compared for the APD group and NAPD group to test the whether the APD group exhibited significantly poorer receptive language ability than students without APD (NAPD group). Significance was not reached for either the *CELF-3:LP* scores or the *PPVT-3* scores on the Mann-Whitney U-test at the 2-tailed level as shown in Table 12. The APD group did not exhibit significantly poorer receptive language ability than the NAPD group. This component of Hypothesis 1 was therefore rejected. However, closer analysis of the results showed a much larger range of standard scores in the APD group (76 to 120) than the NAPD group (95 to 115) on the *CELF-3:LP* test of listening comprehension. The range on the *PPVT-3* was similar for both groups.

TABLE 12:
Mean Standard Scores (Mean=100, SD=15) for Receptive Vocabulary (PPVT-3) with Listening Comprehension (CELF-3:LP) compared by Group

Test	APD group (n=28) mean (SD) & range	NAPD group (n=20) mean (SD) & range	Mann-Whitney U – Test	Significance level (p≤.05, 2-tailed)
PPVT –3	94.89 (11.98) 78-114	98.15 (8.94) 81-114	-1.23	p=0.22 NS
CELF-3: LP	98.79 (13.36) 76-120	105.5 (7.05) 95-115	-1.68	p=0.09 NS

The Spearman's correlation between the *PPVT-3* and *CELF-3:Listening to Paragraphs* was significant for the APD group (*rho* = 0.65, p<0.05), but not for the NAPD group (*rho* = 0.11, p=0.64, ns) as displayed in Table 13.

TABLE 13:
Spearman's Correlations of Receptive Vocabulary (PPVT-3) with Listening Comprehension (CELF-3:LP) by Group.

	Combined APD+NAPD group (n=48)	APD group (n=28)	NAPD group (n=20)
Tests	**PPVT-3**	**PPVT-3**	**PPVT-3**
CELF-3:LP	0.50, p<0.01**	0.65, p<0.01**	-0.11, p=0.64 NS

** significant at 0.01

Performance on the items within the *PPVT-3* was categorised into the percentage of nouns, verbs and descriptors correct i.e. number of nouns correct as a percentage of total noun items attempted. The APD group achieved a significantly lower percentage of receptive verbs correct ($z = -2.6$, $p<0.05$) than NAPD group, but there was no significant difference on the percentage of nouns or descriptors correct. The mean percentage of verbs correct was approximately 63% (mean = 8.43, SD = 3.8) for the APD group compared to approximately 71% (mean = 10.45, SD = 3.1) for the NAPD group. The percentage of verbs correct correlated significantly with the total *PPVT-3* standard score (*rho* = 0.48, $p<0.05$) for the APD group whereas percentage of nouns or descriptors correct did not (*rho* = 0.03, $p=0.87$; *rho* = 0.23, $p=0.24$ respectively). In the APD group, the percentage of verbs correct correlated significantly with the total *PPVT-3* score (*rho* = 0.484, $p<0.05$). When the APD and NAPD groups were combined, the percentage of verbs correct also correlated significantly with the *SR (B)*, *SR (C)*, total *PPVT-3* and *NARA:RC* standard scores as shown in Table 14. Again, the percentage of nouns or descriptors correct did not correlate with the *PPVT-3* scores in the combined APD+NAPD group (*rho* = 0.05, $p=0.73$; *rho* = 0.25, $p=0.08$ respectively). The percentage of verbs (236/374 = 63%), nouns (716/1145 = 62%) and descriptors (254/386 = 65%) correct was similar across categories for the APD group. Interestingly, the percentage of verbs correct was higher (209/291 = 71%) in the NAPD group than percentage of nouns (547/879 = 62%) or descriptors (187/297 = 62%) correct in the same group. As an extension of this finding, the percentage of verbs correct correlated significantly to one of the reading tests, *WRMT:WI*, in both the APD group (*rho* = 0.421, p=0.026) and in the NAPD group (*rho* = 0.541, p=0.014).

TABLE 14:
Spearman's correlations between item categories on the PPVT-3 and standard scores on phonological working memory, vocabulary and reading comprehension tests for the combined APD+NAPD group (n=48).

Item Category	SR (B)	SR (C)	PPVT-3	NARA-3:RC
Nouns	0.124	0.150	0.051	0.258
Verbs	0.295*	0.398**	0.515**	0.297*
Descriptors	0.169	0.136	0.249	0.229

significant at the 0.05 level* * significant at the 0.01 level*

Even though there was no significant difference in overall performance on the *CELF-3:LP*, the APD group performed more poorly on the *CELF-3:LP* Main Idea and Inference comprehension question types, but not significantly so. The NAPD group performed significantly poorer on the *CELF-3:LP* Sequence (z = -1.96, p<0.05) and Prediction (z = -3.29, p<0.05) comprehension question types. There was no significant difference on the Detail question type.

5.3 Group Comparison on Reading Measures

The standard scores on the reading tests (*WRMT* & *NARA-3*) for the APD group and the NAPD group were compared to test whether the APD group exhibited significantly poorer reading ability than the NAPD group. Table 15 shows the mean standard scores on reading tests for both groups. The APD group yielded mean standard scores below the expected mean for age, but within 1 standard deviation below the mean on all reading measures. The *NARA:RA* mean standard score was on the lower border of the average range for the APD group. The results were similar for the NAPD group with the exception of an above average mean for the *WRMT: Word Attack* subtest which also contributes to the *WRMT: Basic Skills Cluster* result. The range for the NAPD group on the *WRMT:Word Attack* subtest fell from within to above the average range, compared to the APD group range which extended from below the average range to within the average range. As there were no significant differences on any of the standardised reading measures the APD group did not have significantly poorer reading ability than the NAPD group, as displayed in Table 15. Therefore, this component of Hypothesis 1 was rejected.

TABLE 15 :

Mean Standard Scores (Mean=100, SD=15) on Reading Tests compared by Group

Test	APD group (n=28) mean (SD) & range	NAPD group (n=20) mean (SD) & range	Mann-Whitney U Test	Significance level ($p \leq 0.05$, 2-tailed)
WRMT- Word Attack Standard Score	96.93 (8.82) 78-113	102.55 (9.56) 90-127	-1.73	p=0.08, NS
WRMT – Word Identification Standard Score	94.93 (8.86) 82-118	98.9 (9.82) 81-123	-1.42	p=0.15, NS
WRMT – Basic Skills Cluster Standard Score[a]	95.11 (9.77) 79-119	100.55 (10.79) 85-127	-1.65	p=0.10, NS
NARA-3 : Reading Accuracy Standard Score	86.46 (9.18) 72-105	88.05 (12.99) 69-116	-0.22	p=0.83, NS
NARA-3 : Reading Comprehension Standard Score	91.32 (12.42) 72-122	93.45 (2.57) 72-115	-0.78	p=0.44, NS
NARA-3 : Reading Rate Standard Score	98.25 (13.89) 69-126	97.80 (15.70) 62-122	-0.21	p=0.83, NS

[a] The scores on the WRMT: Word Attack and Word Identification subtests are combined to calculate the Basic Skills Cluster Score

There was no significant difference in overall performance on the NARA-3:RC, and no significant differences between groups on correct responses to the two question types (recall of details and inferencing) analysed.

Normative data do not exist for the *WRMT: Supplementary Letter Checklist* subtest, but no significant difference was found between raw scores for the two groups on this subtest for either letter naming ($z = -0.24$, $p=0.81$, ns) or letter-sound correspondence ($z = -0.39$, $p=0.70$, ns). A moderate correlation (*rho* = 0.43, $p<0.05$) between letter naming and letter-sound correspondence raw scores was found in the APD group compared to a strong correlation (*rho* = 0.72, $p<0.05$) for the NAPD group, as displayed in Figure 7. It would appear that once a letter or sound is known, the letter name-to-sound association is more readily established in the NAPD group than the APD group.

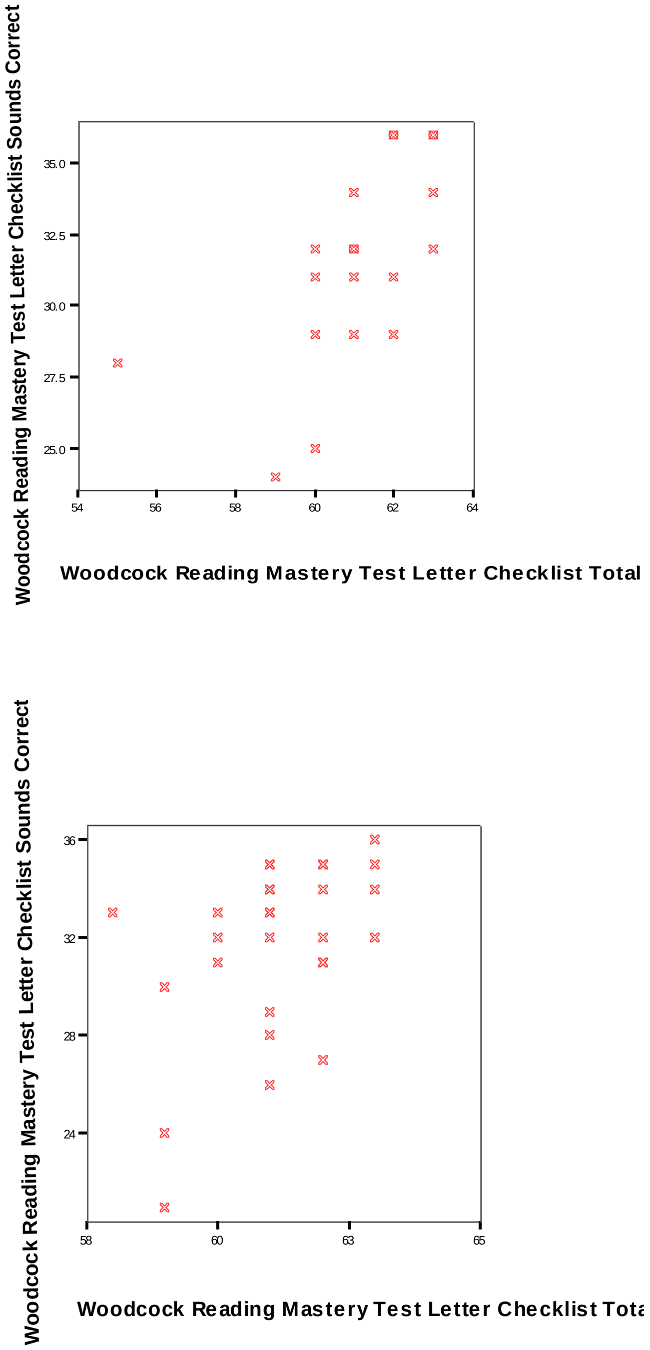


FIGURE 7: Scatterplots showing the correlation between letter-sound correspondence and letter naming for the APD group (n=28) at the top and the NAPD group (n=20) at the bottom.

5.4 Group Comparisons on Severity Measures

Hypothesis 2 stated that the APD group will exhibit a relationship between the degree of APD deficits (severity), receptive language and reading ability. As a reminder, the three severity scores were derived from three severity measures as follows:

- an auditory processing severity score (APS) based upon the total FUSAPB (SSW, CS, DS and SR) and the following two subsets of scores;
- an auditory processing – dichotic listening severity score (AP-DL) based upon the two dichotic tests in the test battery (SSW and CS) and;
- an auditory processing – short-term memory severity score (AP-STM) based upon the two short-term memory tests in the test battery (DS and SR).

As expected, the scores obtained for the three severity measures were significantly lower for the APD group compared to the NAPD group, indicating a higher degree of severity, as shown in Table 16. Note also the greater range of scores for the APD group in Table 16.

TABLE 16:
Mean Severity Scores (Mean=100, SD=15) compared by Group.

Measure	APD group mean (SD)	APD group range	NAPD group mean (SD)	NAPD group range	Mann-Whitney U-test	Sig. level (p≤.01, 2-tailed)
APS score	71.82 (16.41)	13.26 to 94.14	92.20 (8.69)	76.61 to 105.39	-4.66	p<.01 S
AP-DL score	67.43 (21.15)	16.24 to 89.07	92.96 (11.64)	71.50 to 108.31	-4.64	p<.01 S
AP-STM score	80.63 (13.31)	61.48 to 112.2	90.67 (6.69)	78.56 to 99.57	-2.80	p<.01 S

The relationship between the three severity scores (APS, AP-DL & AP-STM) and the receptive language and reading tests was explored, using Spearman's correlations. The results for the combined APD+NAPD group are outlined in Table 17. Significant correlations were found for the *PPVT-3* score with the APS score (*rho* = 0.37, p<0.05), the AP-DL score (*rho* = 0.29, p<0.05) and the AP-STM score (*rho* = 0.55, p<0.05) for the combined APD+NAPD group. Significant correlations were found for the *CELF-3:LP* score with the APS score (*rho* = 0.29, p<0.05) and the AP-STM score (*rho* = 0.38, p<0.05) for the combined APD+NAPD group.

No significant correlations were found between the reading scores and severity scores for the combined APD+NAPD group. The degree of AP deficits was not significantly correlated with reading ability in the combined group.

TABLE 17*:*

Spearman's Correlations (p≤.05) of the Auditory Processing Score (APS), Auditory Processing- Dichotic Listening score (AP-DL) and Auditory Processing –Short-Term Memory score (AP-STM) with the Language Assessments and Reading Comprehension Assessment for the Combined APD+NAPD Group (n=48).

Test	APS: Auditory processing score derived from SSW,CS, DS and SR tests	AP-DL: AP score derived from SSW & CS tests	AP-STM: AP score derived from DS and SR tests
PPVT-3	0.37, p=0.01**	0.29, p=0.05*	0.55, p<0.01**
CELF-3:LP	0.29, p=0.01*	0.22, p=0.13 NS	0.38, p=0.01**
WRMT:WA	0.10, p=0.50, NS	0.05, p=0.75 NS	0.23, p=0.11 NS
WRMT:WI	0.05, p=0.75 NS	-0.01, p=0.93 NS	0.21, p=0.15 NS
WRMT:BS	0.10, p=0.51 NS	0.04, p=0.82 NS	0.25, p=0.09 NS
NARA-3:RA	-0.09, p=0.56 NS	-0.14, p=0.34 NS	0.06, p=0.67 NS
NARA-3:RC	0.08, p=0.60 NS	-0.01, p=0.95 NS	0.27, p=0.07 NS
NARA-3:RR	-0.13, p=0.40, NS	-0.12, p=0.41 NS	-0.02, p=0.92 NS

*significant at 0.05 ** significant at 0.01

KEY: PPVT-3 = Peabody Picture Vocabulary Test-3; CELF-3:LP = Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs; WRMT: WA, WI & BS = Woodcock Reading Mastery Tests : Word Attack, Word Identification & Basic Skills; NARA-3: RA, RC & RR = Neale Analysis of Reading Ability- 3: Reading Accuracy, Reading Comprehension & Reading Rate

The results of the severity correlations for the APD group are displayed in Table 18. Moderate-to-strong correlations were found for the PPVT-3 score with both the APS score (*rho* = 0.47, $p<0.05$) and the AP-STM score (*rho* = 0.58, $p<0.05$) in the APD group. In relation to Hypothesis 2 only receptive vocabulary, but not listening comprehension, was significantly correlated with the degree of AP deficits in the APD group.

No significant correlations were found between the reading scores and severity scores for the APD group. The degree of AP deficits was not significantly correlated with reading ability. This suggests that while there is a relationship between the degree of AP deficits and language performance, language performance is only one aspect of reading performance.

TABLE 18:

Spearman's Correlations (p≤0.05) of the Auditory Processing Score (APS), Auditory Processing- Dichotic Listening (AP-DL) and Auditory Processing- Short -Term Memory (AP-STM) score with the Language Assessments and Reading Comprehension Assessment for the APD group (n=28).

Test	APS: Auditory processing score	AP-DL: AP score derived from SSW & CS tests	AP-STM: AP score derived from DS & SR tests
PPVT-3	0.47, p=0.01*	0.31, p=0.11 NS	0.58, p<0.01**
CELF-3:LP	0.21, p=0.28 NS	0.10, p=0.62 NS	0.32, p=0.10 NS
WRMT:WA	0.11, p=0.58 NS	-0.22, p=0.25 NS	0.08, p=0.69 NS
WRMT:WI	-0.10, p=0.61 NS	-0.23, p=0.24 NS	0.14, p=0.49 NS
WRMT:BS	-0.07, p=0.71 NS	-0.21, p=0.28 NS	0.15, p=0.44 NS
NARA-3:RA	-0.06, p=0.78 NS	-0.22, p=0.27 NS	0.09, p=0.63 NS
NARA-3:RC	0.06, p=0.75 NS	-0.17, p=0.39 NS	0.31, p=0.11 NS
NARA-3:RR	-0.05, p=0.80 NS	-0.10, p=0.60 NS	0.14, p=0.49 NS

*significant at 0.05 ** significant at 0.01

KEY: PPVT-3 = Peabody Picture Vocabulary Test-3; CELF-3:LP = Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs; WRMT: WA, WI & BS = Woodcock Reading Mastery Tests : Word Attack, Word Identification & Basic Skills; NARA-3: RA, RC & RR = Neale Analysis of Reading Ability- 3: Reading Accuracy, Reading Comprehension & Reading Rate

To investigate the relationship between the extension AP test scores (*AFG* plus the two non-speech –tests, the *PPS-C* and *RGDT*) and the severity scores, Spearman's correlations were performed for the APD group. The results are set out in Table 19. The results again showed that the *PPS-C(R)* and *PPS-C(RT)* scores correlate with the AP-STM scores: we know from previous analysis that this is likely to be due to the significant correlation between the *PPS-C* scores and the *SR* scores, as outlined in Table 11. The *PPS-C(L)* correlated previously with the *SR(B)*, but does not correlate significantly with the AP-STM scores. The *RGDT* score which correlated with the *DS* score, also does not correlate with the AP-STM score possibly suggesting that the *DS* and *SR* tests are tapping discrete aspects of auditory memory or auditory attention.

Further, the AP-DL score correlated significantly with both *SR(B)* and *SR(C)* scores indicating that interhemispheric transfer deficits may contribute to PWM performance.

TABLE 19:

Spearman's Correlations (p≤0.05) of the Auditory Processing Score (APS) and Auditory Processing- Dichotic Listening (AP-DL) and Auditory Processing –Short Term Memory (AP-STM) with the Auditory Short-Term Memory Tests and Non-Speech Tests for the APD Group (n=28).

Test	**APS: Auditory processing score**	**AP-DL: AP score derived from SSW & CS tests**	**AP-STM: AP score derived from DS and SR tests**
DS	[0.44, p=0.02*]	0.33, p=0.09 NS	[0.55, p<0.01**]
SR(B)	[0.71, p<0.01**]	0.57, p<0.01**	[0.86, p<0.01**]
SR(C)	[0.61, p<0.01**]	0.40, p=0.04*	[0.84, p<0.01**]
AFG	0.19, p=0.33 NS	0.20, p=0.31 NS	0.29, p=0.14 NS
PPS-C (L)	0.21, p=0.28 NS	0.17, p=0.40 NS	0.27, p=0.17 NS
PPS-C (LT)	0.15, p=0.43 NS	0.10, p=0.60 NS	0.19, p=0.33 NS
PPS-C (R)	0.30, p=0.12 NS	0.27, p=0.17 NS	0.40, p=0.04*
PPS-C(RT)	0.34, p=0.08 NS	0.27, p=0.16 NS	0.41, p=0.03*
RGDT	-0.10, p=0.60 NS	-0.10, p=0.62 NS	0.22, p=0.25 NS

*significant at 0.05 ** significant at 0.01

KEY: [ ] = signifies tests that are components of the severity score therefore would be expected to correlate significantly with that score; DS = Digit Span test; SR = Sentence Recall test : (B) =Basal, (C)=Ceiling; AFG = Auditory Figure Ground test; PPS-C = Pitch Pattern Perception test – non-speech test, (L)=LeftEar, (R)=Right Ear, (LT)=Left Total, (RT)=Right Total; RGDT = Random Gap Detection Test – non-speech test

5.5 Relationship between Language and Reading Measures

In order to test Hypothesis 3 stating that there will be significant correlations between PWM, receptive language and reading ability, the relationship between the language scores and reading scores was firstly explored. Analysis of the relationship between the language scores and reading scores showed moderate-to-strong Spearman's correlations of both the *PPVT-3* scores to the *NARA-3:RC* scores (*rho* = 0.53, $p<0.05$) and the *CELF-3:LP* to the *NARA-3:RC* scores (*rho* = 0.43, $p<0.05$) for the APD group as shown in Table 20. However, the language tests did not correlate with the word reading tests (*WRMT:WA*, *WRMT:WI*), text reading accuracy (*NARA:RA*) or text reading rate (*NARA:RR*). This gives a clear result that language skills have the greatest effect on reading comprehension, of all the reading skills. The only correlation to reading rate (*NARA:RR*), a measure of fluency, was the word identification scores (*WRMT:WI*) as shown in Table 20. No significant correlations between the receptive language tests and the reading tests were found for the NAPD group. Mean reading scores fell within the average range on all reading tests for the NAPD group though the mean standard score on the *NARA:RA* was 88.05 (mean = 100, SD = 15, range = 85-115). However, a lack of correlation between receptive language performance and reading accuracy indicates that low performance on reading accuracy cannot be attributed to language ability in this group.

The relationship between the *RCPM* measure of non-verbal intellectual ability, and the language and reading measures was explored using Spearman's correlations. The *RCPM* was moderately correlated with the measure of reading rate only (*NARA:RR*: *rho* = 0.381, $p<0.05$) in the APD group, but not the NAPD group (*rho* = -0.251, p=0.287, ns). There were no significant correlations for the NAPD group. There was a moderate correlation between the RCPM and one reading test, the WRMT:WI for the combined APD + NAPD group (*rho* = 0.35, $p<0.05$).The results suggest that non-verbal intellectual ability is not a major contributing factor to overall reading performance, but may make a contribution to reading fluency.

TABLE 20:

Spearman's Correlations (p≤0.05) between Language and Reading Measures for the APD Group (n=28)

Test	PPVT-3	CELF-3:LP	WRMT: WA	WRMT: WI	WRMT: BS	NARA-3:RA	NARA-3:RC	NARA-3:RR
PPVT-3	1.0							
CELF-3:LP	0.65, p<0.01 **	1.0						
WRMT:WA	0.29, p=0.14 NS	-0.01, p=0.97 NS	1.0					
WRMT:WI	0.37, p=0.05 NS	0.14, p=0.48 NS	0.89, p<0.01 **	1.0				
WRMT:BS	0.37, p=0.05 *	0.09, p=0.66 NS	0.96, p<0.01 **	0.98, p<0.01 **	1.0			
NARA-3:RA	0.29, p=0.14 NS	0.19, p=0.34 NS	0.64, p<0.01 **	0.77, p<0.01 **	0.75, p<0.01 **	1.0		
NARA-3:RC	0.53, p<0.01 **	0.43, p=0.02 *	0.62, p<0.01 **	0.72, p<0.01 **	0.72, p<0.01 **	0.89, p<0.01 **	1.0	
NARA-3:RR	0.24, p=0.23 NS	0.24, p=0.22 NS	0.20, p=0.30 NS	0.41, p=0.03 *	0.36, p=0.08 NS	0.34, p=0.07 NS	0.22, p=0.26 NS	1.0

*significant at 0.05 ** significant at 0.01

KEY: PPVT = Peabody Picture Vocabulary Test-3; CELF:LP = Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs; WRMT: WA, WI & BS = Woodcock Reading Mastery Tests : Word Attack, Word Identification & Basic Skills; NARA-3: RA, RC & RR = Neale Analysis of Reading Ability- 3: Reading Accuracy, Reading Comprehension & Reading Rate

5.6 Relationship between Auditory Processing, Language and Reading Measures

The second stage of analysis to test Hypothesis 3 required exploration of the relationship between the auditory processing tests (including SR as the measure of PWM) and the language and reading tests. Table 21 displays the correlations between the auditory processing tests and both the language and reading tests. Seven auditory processing tests were administered in all. The *DS*, *AFG* and *RGDT* tests showed no correlation with language or reading measures. The other four tests (*SSW*, *CS*, *SR* and *PPS-C*) correlated significantly with the language tests, reading tests or both for the APD group.

Significant correlations were found between auditory processing results and the language measures for the APD group only, displayed in Table 21. Spearman's correlations showed that low performance on the *SSW(RNC)*, *SSW(LNC)*, *CS(W)*, *SR(B)* and *SR(C)* correlated with low scores on the *PPVT-3*. Note that it has been previously mentioned that both *SSW(RNC)* and *SSW(LNC)* scores were moderately correlated with *SR(C)* performance and that these three AP tests correlated in the moderate-to-strong range with the *PPVT-3* scores. Low performance on the *SR(C)* was also correlated with low performance on the *CELF-3:LP*. No correlations were found for the NAPD group between AP performance and either of the language tests. This is not surprising given that all AP mean standard scores (except the *DS* test) and the mean standard scores on both receptive language tests fell within the average range for the NAPD group.

While there was no significant difference between the groups on overall reading ability, the correlations between the auditory processing tests and specific reading tests identify the groups as different. Three of the seven auditory processing tests (*CS*, *SR* & *PPS-C*) correlated significantly with the reading tests for the APD group, as displayed in Table 21. For the NAPD group, only one AP test correlated with reading abilities: the *PPS-C (RT)* correlated strongly with the *WRMT:WI* (*rho* = 0.51, p<0.05) and *NARA-3:RC* (*rho* = 0.56, p<0.05).

As shown in Table 21, the PWM measure (Sentence Recall-Ceiling) correlated significantly with performance on tests on the *PPVT-3* test of receptive vocabulary (*rho* = 0.60, p<0.05), the *CELF-3:LP* test of listening comprehension (*rho* = 0.42, p<0.05) and the *NARA:RC* measure of reading comprehension (*rho* = 0.39, p<0.05). Given both the *PPVT-3* and *CELF-3:LP* receptive language tests also correlated significantly with reading comprehension (*rho* = 0.53, p<0.05 and *rho* = 0.43, p<0.05 respectively) as per Table 20, Hypothesis 3 was accepted. There were significant correlations between PWM, language and reading ability in the APD group.

TABLE 21:

Spearman's Correlations (p≤0.05) between Auditory Processing Tests and the Receptive Language and Reading Tests for the APD Group (n=28).

Test	PPVT-3	CELF -3:LP	WRMT :WA	WRMT :WI	WRMT: BS	NARA -3:RA	NARA -3: RC	NARA-3:RR
SSW (RNC)	0.45, p=0.02 *	0.23, p=0.24 NS	-0.06, p=0.78, NS	-0.01, p=0.94 NS	-0.02, p=0.92 NS	-0.03, p=0.88 NS	-0.01, p=0.97 NS	0.13, p=0.50 NS
SSW (LNC)	0.53, p<0.01 *	0.17, p=0.39 NS	-0.03, p=0.86, NS	0.17, p=0.40 NS	0.10, =0.61 NS	0.10, p=0.62 NS	0.16, p=0.42 NS	0.33, p=0.08 NS
SSW (RC)	0.27, p=0.17, NS	0.19, p=0.33 NS	0.04, p=0.84 NS	-0.03, p=0.89 NS	0.00, p=0.98 NS	-0.08, p=0.67 NS	-0.01, p=0.96 NS	0.08, p=0.69 NS
SSW (LC)	0.16, p=0.43 NS	-0.05, p=0.80 NS	0.17, p=0.39 NS	0.11, p=0.59 NS	0.13, p=0.51 NS	-0.01, p=0.97 NS	0.02, p=0.91 NS	-0.18, p=0.35 NS
CS(S)	-0.18, p=0.35 NS	-0.18, p=0.37, NS	-0.19, p=0.33 NS	-0.13, p=0.50 NS	-0.14, p=0.48 NS	0.01, p=0.95 NS	-0.10, p=0.63 NS	-0.15, p=0.45 NS
CS(W)	-0.40, p=0.02 *	-0.27, p=0.17 NS	-0.12, p=0.53 NS	-0.31, p=0.11 NS	-0.24, p=0.22 NS	-0.28, p=0.14 NS	-0.26, p=0.19 NS	-0.42, p=0.03 *
DS	0.34, p=0.08 NS	0.02, p=0.93 NS	0.13, p=0.35 NS	0.18, p=0.35 NS	0.19, p=0.34 NS	0.16, p=0.40 NS	0.27, p=0.16 NS	0.25, p=0.19 NS
SR(B)	0.51, p=0.01 **	0.28, p=0.15 NS	0.19, p=0.35 NS	0.20, p=0.30 NS	0.23, p=0.25 NS	0.17, p=0.38 NS	0.30, p=0.13 NS	0.07, p=0.72 NS
SR(C)	0.60, p=0.0 **	0.42, p=0.03 *	0.01, p=0.96 NS	0.16 p=0.56 NS	0.11, p=0.58 NS	0.12, p=0.56 NS	0.39 p=0.04 *	0.17, p=0.38 NS

Test	PPVT-3	CELF-3:LP	WRMT:WA	WRMT:WI	WRMT: BS	NARA-3:RA	NARA-3: RC	NARA-3:RR
AFG	0.10, p=0.63 NS	-0.08, p=0.69 NS	-0.08, p=0.70 NS	0.01, p=0.97 NS	-0.04, p=0.84 NS	-0.14, p=0.47 NS	-0.12, p=0.53 NS	-0.14, p=0.49 NS
PPS-C (R)	-0.00, p=0.99 NS	-0.17, p=0.38 NS	0.33, p=0.09 NS	0.30, p=0.12 NS	0.33, p=0.09 NS	0.04, p=0.83 NS	0.10, p=0.63 NS	0.13, p=0.50 NS
PPS-C (RT)	0.13, p=0.52 NS	-0.11, p=0.59 NS	0.39, p=0.04 *	0.37, p=0.05 NS	0.39, p=0.04 *	0.05, p=0.79 NS	0.13, p=0.51 NS	0.12, p=0.54 NS
PPS-C (L)	0.09, p=0.63 NS	-0.32, p=0.10 NS	0.55, p<0.01 **	0.46, p=0.01 *	0.53, p<0.01 **	0.16, p=0.42 NS	0.15, p=0.46 NS	0.03, p=0.89 NS
PPS-C (LT)	0.16, p=0.43 NS	-0.23, p=0.23 NS	0.51, p=0.01 **	0.53, p<0.01 **	0.56, p<0.01 **	0.25, p=0.20 NS	0.26, p=0.18 NS	0.04, p=0.86 NS
RGDT	0.26, p=0.19 NS	0.09, p=0.67 NS	0.10, p=0.60 NS	0.13, p=0.52 NS	0.10, p=0.60 NS	-0.18, p=0.35 NS	-0.03, p=0.89 NS	0.03, p=0.89 NS

*significant at 0.05 ** significant at 0.01

KEY: SSW = Staggered Spondaic Word test; (RNC) = Right Non-competing condition, (LNC) = Left non-competing condition, (RC) = Right competing condition, (LC) = Left competing condition; CS = Competing Sentences test; (S) = Strong, (W) = Weak; DS = Digit Span test; SR = Sentence Recall test : (B) =Basal, (C)=Ceiling; AFG = Auditory Figure Ground; PPS-C = Pitch Pattern Perception test – non-speech test, (L) = LeftEar, (R) = Right Ear, (LT) = Left Total, (RT) = Right Total; RGDT = Random Gap Detection Test – non-speech test; PPVT-3 = Peabody Picture Vocabulary Test-3; CELF-3:LP = Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs; WRMT: WA, WI & BS = Woodcock Reading Mastery Tests : Word Attack, Word Identification & Basic Skills; NARA-3: RA, RC & RR = Neale Analysis of Reading Ability- 3: Reading Accuracy, Reading Comprehension & Reading Rate

5.7 Discriminant Analysis

Discriminant analysis showed that the *SSW(LC)* and *SSW(RC)* subtests were the most sensitive discriminators of APD vs. NAPD group allocation. The same result was found when only the FUSAPB tests were entered (*SSW, CS, DS & SR*) and also when all extension AP tests (*AFG, PPS-C, RGDT*), language (*PPVT-3, CELF:LP*) and reading tests (*WRMT-R, NARA-3*) were entered. Discriminant analysis confirmed correct classification of participants to the APD or NAPD group with 89.6% accuracy, based on performance on the AP tests. The combined performance on the FUSAPB, language and reading tests discriminated group classification with 91.7% accuracy as outlined below.

			Predicted Group Membership		Total
		APD/ NAPD	APD	NAPD	APD
Original	Count	APD	26	2	28
		NAPD	3	17	20
	%	APD	92.9	7.1	100.0
		NAPD	15.0	85.0	100.0

a 89.6% of original grouped cases correctly classified.

			Predicted Group Membership		Total
		APD/ NAPD	APD	NAPD	APD
Original	Count	APD	26	2	28
		NAPD	2	18	20
	%	APD	92.9	7.1	100.0
		NAPD	10.0	90.0	100.0

a 91.7% of original grouped cases correctly classified.

The two misclassified APD participants exhibited an atypical pattern of performance on the AP tests. One participant performed above the mean for the APD group on the *SSW(LC)* test and the other performed above the mean for the *DS* and *SR* tests. The misclassified NAPD participants, identified under discriminant analysis, performed poorly on only one of the two dichotic tests (*SSW* or *CS*) and within the average range on the auditory memory tests, therefore not fulfilling the criteria for APD diagnosis.

The finding of the *SSW(LC)* and *SSW(RC)* as highly discriminating of APD diagnosis led to further investigation of the relationship of these two dichotic listening variables to PWM, language and reading. While the *SSW(LC)* and *(RC)* had not correlated significantly with *SR(C),* language or reading in the APD group, the profile of the misclassified participants prompted an evaluation of the combined APD+NAPD group. When *SSW(LC)* and *(RC)* scores were compared to PWM, language and reading tests in the combined APD+NAPD group, this yielded the following interesting findings. The *SSW(RC)* correlated significantly with the *SR(B)* (*rho* = 0.46, $p<0.05$), *SR(C)* (*rho* = 0.37, $p<0.05$), *PPS-C(RT)* (*rho* = 0.29, $p<0.05$) and *PPVT-3* (*rho* = 0.32, $p<0.05$). The *SSW(LC)* correlated significantly with both *SR(B)* (*rho* = 0.38, $p<0.05$) and *SR(C)* (*rho* = 0.46, $p<0.05$). An important finding was the considerable change in the degree of correlation between the *SSW(LC)* and the *SR(C)* scores between the APD group (*rho* = 0.14, $p=0.48$, ns) and the combined APD+NAPD group (*rho* = 0.38, $p<0.05$, sig.), suggesting that a relationship between deficits in binaural integration of auditory input and PWM may exist.

5.8 Multiple Regression

To determine the contribution of independent variables to reading performance, backward and forward hierarchical multiple regression analyses were performed for text reading accuracy standard scores (*NARA-3:RA*) and reading comprehension standard scores (*NARA-3:RC*) for the APD group (n = 28). Initially, six independent variables were selected on the basis of the existing literature. These six variables were the test of non-verbal intellectual ability (*RCPM*), receptive vocabulary (*PPVT-3*), listening comprehension (*CELF-3:LP*), word attack (*WRMT:WA*), word identification (*WRMT:WI*) and *SR(C).* The *SSW(LC)* was also included as it was identified as the most discriminating variable of APD diagnosis under discriminant analysis.

The models of best fit for both backward and forward regression for *NARA-3:RA* attributed the strongest contribution to *WRMT: Word Identification* (R^2 = 54.1% , t = 5.54, $p<0.05$). The models of best fit for both backward and forward regression for the *NARA:RC* attributed the strongest contribution to both the *WRMT: Word Identification* (R^2 = 60.2%, t =4 .71, $p<0.05$) and the *SR (C)* (R^2 = 60.2%, t = 3.44, $p<0.05$). The results for multiple regression analysis are displayed in Table 22.

When other text reading measures were inserted into multiple regression the model of best fit for reading accuracy included reading comprehension, word identification, word attack, vocabulary and *PPS-C(RT)* and could account for 88.75% in performance. Reading comprehension alone accounted for 75% of the variance, but collinearity between reading comprehension and reading accuracy could be considered an issue, given a correlation of *rho* = .866 ($p<0.01$). Word identification alone explained 54.1% of the variance, so clearly word identification does not solely account for reading accuracy.

When other text reading measures were inserted into multiple regression the model of best fit for reading comprehension included reading accuracy, word identification, word attack, vocabulary and *SR(C)* and could account for 96.4% in performance. Reading accuracy alone accounted for 75% of the variance, but again, collinearity between reading comprehension and reading accuracy could be considered an issue. Word identification explained 41.4% of the variance, so clearly word identification alone does not solely account for reading comprehension either.

TABLE 22:
The Model of Best Fit for NARA-3: Reading Accuracy and NARA-3 Reading Comprehension Standard Scores: Forward and backward regression analysis.

Dependent Variable	Indep. Variable	Variance explained	Total R	R^2	Unstand. β	Standard. β	*t*	Sig. level
NARA:RA	WRMT: WI	54.1%	73.6%	54.1 %	0.762	0.736	5.54	<.01
NARA:RC	WRMT: WI	41.4%	77.6%	60.2 %	0.863	0.597	4.71	<.01
	SR(C)	25%			0.316	0.437	3.44	0.01

To take the next step, using forward regression, when AP, language and reading measures were entered for word identification (*WRMT:WI*), 74.3% of the variance could be explained by the *PPS(LT), PPVT-3*, *CS(W)* and *WRMT:WA* scores. Of these the *PPS(LT)* score was the strongest contributing factor, accounting for 24.9% of the variance alone.

5.9 Descriptive Error Analysis

Reading errors (875 items in total) on the *NARA-3* were firstly analysed in terms of whether the error could be classified as 'meaning retained' or 'meaning lost'. Fewer errors retained meaning in the larger APD group (n = 28) compared to the smaller NAPD group (n = 20). Eighty-three percent of the reading errors made by the APD participants were inconsistent with the intended meaning of the text compared to 78% of reading errors made by NAPD participants. Descriptive results are detailed in Table 23.

TABLE 23:
Error Totals for the APD Group compared to the NAPD Group.

Error Category	APD group (n=28)	Mean (SD)	Percentage	NAPD group (n=20)	Mean (SD)	Percentage
Meaning Lost	407	14.55 (7.36)	83%	289	14.6 (9.66)	78%
Meaning Retained	84	3.0 (2.80)	17%	83	4.6 (2.28)	22%
Total Errors	491	17.54 (9.13)	100%	372	19.20 (10.32)	100%

Further analysis of the seven *RAP* error categories indicated minor differences in the pattern that characterised each group. The APD group (n = 28) made fewer visual errors, deletions, recasts and decoding errors on average than the NAPD group (n = 20). Therefore, while the NARA:RA scores were low average in both the APD and NAPD groups, the errors indicate that different underlying processes and strategies manifest in the pattern of the scores. The results are displayed in Table 24. Hypothesis 4 was accepted: The *RAP* analysis showed differences in the reading error patterns of the APD group compared to the NAPD group.

In summary, the error analysis showed that a greater mean number of errors lost the intended meaning of the text for the APD group compared to the NAPD group. The APD group also made fewer visual errors, deletion errors, decoding errors and recasts compared to the NAPD group.

TABLE 24:

Descriptive Analysis of Error Categories compared by Group

Error Category	APD group (n=28)	Mean	NAPD group (n=20)	Mean
Visual	11	0.39	12	0.60
Recast	12	0.43	12	0.60
Deletions	48	1.70	41	2.05
Additions	43	1.50	28	1.40
Substitutions	209	7.46	153	7.65
Decoding	156	5.57	121	6.05
Other	12	0.42	5	0.25

Note. The different group size affects the comparison of raw tallies, therefore refer to mean score.

5.10 Summary of Study One

There were no significant differences in the chronological age, gender composition or non-verbal intellectual abilities of the APD group (n = 28) compared to the NAPD group. The APD performed significantly poorer on the *Staggered Spondaic Word (SSW)*, *Competing Sentences (CS)* and *Sentence Recall (SR)* subtests within the Flinders University standard auditory processing battery (FUSAPB), but not on the *Digit Span (DS)* test compared to the NAPD group. *DS* scores were below average in both the APD and NAPD groups. Discriminant analysis determined that performance on the *SSW (LC)* was the most discriminating variable for determination of group membership.

Significantly poorer performance on the *SR* test indicates poorer phonological working memory (PWM) ability in the APD group compared to the NAPD group. There was no significant difference between receptive language or reading performance between the two groups.

As expected, the degree of AP severity in the APD group was greater on the Auditory Processing Severity score (APS), Auditory Processing- Dichotic Listening score (AP-DL) and Auditory Processing – Short Term Memory score (AP-STM). An important finding was the significant correlation between the AP-DL severity score (derived from the *SSW* and *CS* tests) with both *SR(B)* and *SR(C)* scores indicating that interhemispheric transfer deficits may contribute to PWM performance. This was supported by a significant correlation between the *SSW(LC)* and the *SR(C)* scores in the combined APD+NAPD group. There was also a moderate correlation between the *PPS(RT)* and both the *SR(C)* and AP-STM severity measure.

In the combined APD+NAPD group, the APS and AP-STM scores correlated significantly with the receptive language scores. In the APD group the APS and AP-STM scores correlated significantly with the Peabody Picture Vocabulary Test– 3 *(PPVT-3)* scores but not the Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs (*CELF-3:LP*) scores. The severity scores were not significantly correlated with the reading scores.

Moderate-to-strong correlations were found between PWM ability on the *SR(C)* and both receptive language tests, the *PPVT-3* and *CELF-3:LP*, and the Neale Analysis of Reading Ability: Reading Comprehension *(NARA:RC)* scores, but not to the reading accuracy (*NARA:RA*) or the reading rate (*NARA:RR*) scores, supporting an interaction between PWM, receptive language and reading comprehension. Moderate-to-strong correlations were also found for the *Pitch Pattern Sequence (RT), (L)* and *(LT)* scores with the word reading tests, the *Woodcock Reading Mastery Tests*: *Word Attack (WRMT:WA)* and *Word Identification (WRMT:WI)* subtests in the APD group. The *WRMT:WA* and *WRMT:WI* correlate significantly with the *NARA: Reading Accuracy* and *NARA: Reading Comprehension* scores. The *WRMT:WI* also correlated significantly with the *NARA: Reading Rate* scores. Strong correlations were found for the *PPS (RT)* and the *WRMT:WI* and *NARA:RC* in the NAPD group. This supports an interaction between frequency discrimination, word reading and all aspects of text reading. The inference is that frequency discrimination may have an impact on the quality and specificity of phonological representations in long-term memory, affecting phonological working memory.

Multiple regression analysis determined that *WRMT: Word Identification* subtest explained 54.1% of the variance in the model of best fit for the *NARA: Reading Accuracy* scores. Together the *WRMT:Word Identification* and *SR(C)* scores explained 60.2% of the variance in the model of best fit for the *NARA: Reading Comprehension* scores. This shows that both efficient word identification *and* PWM skills are essential for reading comprehension to occur.

The discriminant analysis determined confidence in group allocation. The comparative analysis determined that the major difference between the APD and NAPD groups was PWM performance. The correlational analysis informs the relationship between a) performance on dichotic tasks and PWM performance and b) PWM performance and receptive language ability. Finally, regression analysis showed that 54.1% of variance for reading accuracy performance was explained by word identification, but 60.2 % of variance for reading comprehension was explained by both word identification and PWM performance. Therefore, regression analysis showed that PWM abilities are related to dichotic listening performance and showed a) a significant relationship to receptive language and b) made a strong contribution to reading comprehension.

CHAPTER SIX

Results

6.0 Study Two

The analysis for Study Two compares the receptive language and reading performance of a subgroup of the APD group (n = 21) to a reading-age matched Average reader group (n = 21), matched on the *NARA:RA* raw scores and age equivalency scores as well as gender and SES. The language and reading abilities of the matched APD group and Average group were compared using the non -parametric Wilcoxon Signed Rank Test for matched pairs, appropriate to the test design, to determine any significant difference in performance. Spearman's correlations between the auditory processing results, language and reading results were then performed for each group. Descriptive reading error analysis was then performed.

As reported in the Method section, there was a significant difference in the chronological age of the two groups, with the Average group being significantly younger. There was also a significant difference in standard scores on the *RCPM* though both mean scores fell within the average range. There was no significant difference in the gender composition of the two groups.

6.1 Group Comparisons on Receptive Language and Reading Measures

Wilcoxon Signed Rank analysis for matched pairs showed significantly poorer receptive language abilities with both poorer vocabulary standard scores ($z = -2.88$, $p<0.05$) and poorer listening comprehension standard scores ($z = -2.58$, $p<0.05$) for the APD group compared to the Average group.

The APD group were significantly poorer readers than the Average group, based on reading *standard scores* for word attack ($z = -3.48$, $p<0.05$), word identification ($z = -3.55$, $p<0.05$), reading accuracy ($z = -4.02$, $p<0.05$) and reading comprehension ($z = -3.50$, $p<0.05$). Reading rate was not significantly different between the APD and Average groups ($z = -1.88$, $p<0.05$, ns). For clarity, although the two groups were matched on *NARA:RA* raw scores and age equivalency scores, the standard scores obtained by the two groups on the *NARA:RA* were significantly different. The findings in relation to receptive language and reading ability are displayed in Table 25. Hypothesis 5 was accepted. The APD group exhibited significantly poorer receptive language and reading ability than the Average group.

TABLE 25:

Mean Standard Scores (Mean=100, SD=15) on Receptive Language and Reading Measures compared by Group.

Test	APD group (n=21) mean (SD) & range	Average group (n=21) mean (SD) & range	Wilcoxon Signed Ranks test	Significance level (p<0.05, 2-tailed)
PPVT-3 Standard Score	95.67 (12.37) 78-114	105.33 (5.13) 98-117	-2.87 S	p<0.01 S
CELF-3: Listening To Paragraphs Standard Score	97.67 (13.64) 76-120	108.71 (11.47) 85-125	-2.60 S	p=0.01 S
WRMT- Word Attack Standard Score	97.52 (7.47) 81-112	110.00 (8.13) 95-124	-3.48 S	p<0.01 S
WRMT – Word Identification Standard Score	95.19 (6.65) 82-105	105.14 (8.38) 90-120	-3.55 S	p<0.01 S
WRMT – Basic Skills Cluster Standard Score[a]	95.52 (7.65) 79-109	107.76 (8.49) 90-123	-3.69 S	p<0.01 S
NARA-3 : Reading Accuracy Standard Score	86.14 (9.37) 72-105	102.48 (7.27) 91-115	-4.02 S	p<0.01 S
NARA-3 : Reading Comprehension Standard Score	91.33 (14.13) 72-122	105.00 (6.78) 92-116	-3.50 S	p<0.01 S
NARA-3 : Reading Rate Standard Score	98.43 (14.95) 69-126	105.86 (13.70) 82-138	-1.88 NS	p=0.06 NS

[a] The scores on the WRMT: Word Attack and Word Identification subtests are combined to calculate the Basic Skills Cluster Score

Analysis of the raw scores on the *WRMT: Supplementary Letter Checklist* for letter naming were also significantly poorer for the APD group compared to the Average group ($z = -3.47$, $p<0.05$), but there was no significant difference on the raw scores for letter-sound correspondence ($z = -0.74$, $p \geq 0.05$, ns). A very strong correlation (*rho* = 0.99, $p<0.05$) between letter naming and letter-sound correspondence raw scores was found in the Average group compared to a non-significant correlation (*rho* = 0.33, $p>0.14$, ns) for the APD group as shown in the scatterplots in Figure 8 below.

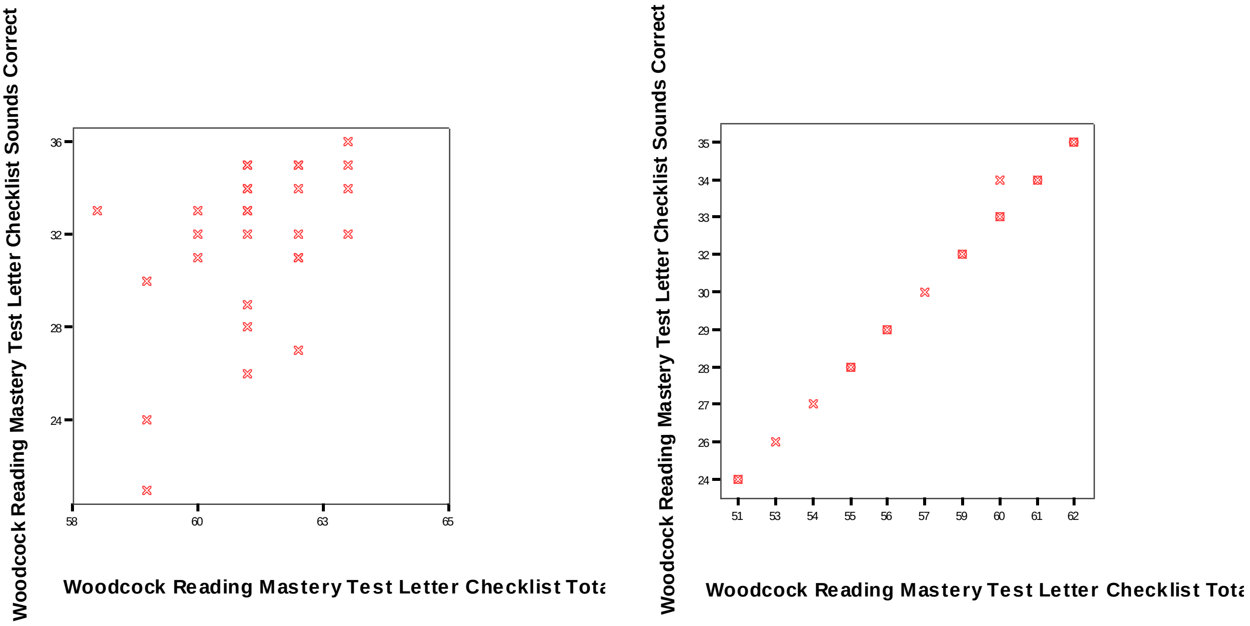


FIGURE 8: Scatterplots showing the correlation between letter-sound correspondence and letter naming for the APD group (n = 21) on the left hand side and the Average group (n = 21) on the right hand side.

6.2 Relationship between Language and Reading Measures

Hypothesis 6 states that there will be significant correlations between PWM, language ability and reading ability. This was previously upheld in Hypothesis 3 within Study One, but is repeated with the APD subgroup in Study Two to determine whether this important relationship is maintained within a smaller group. Firstly, the correlations within and between language scores and reading scores in the APD group were examined. Analysis showed a strong correlation between the *PPVT-3* scores and the *CELF:LP* scores (*rho* = 0.64, $p<0.05$). All language and reading tests were correlated with the *NARA-3:RC* scores, with the exception of the *NARA-3:RR* score. The results are detailed in Table 26. Therefore, a significant relationship between receptive language ability and reading ability was confirmed in the APD subgroup.

In addition, significant correlations were found between the *WRMT:WA* and *WRMT:WI* subtests (*rho* = 0.77, $p<0.05$) and both the *WRMT:WA* & *WRMT:WI* subtests to *NARA-3:RA* (*rho* = 0.63, $p<0.05$ and *rho* = 0.84, $p<0.05$ respectively) in the APD group. This suggests that both word decoding skill and word recognition skill contribute to text reading accuracy.

TABLE 26:

Spearman's Correlations ($p < 0.05$) between the Receptive Language and Reading Measures for the Reading-age Matched APD Group (n=21).

Test	PPVT -3	CELF-3:LP	WRMT: WA	WRMT: WI	WRMT : BS	NARA-3:RA	NARA-3:RC	NARA-3:RR
PPVT-3	1.0							
CELF-3:LP	0.65, p<0.01 **	1.0						
WRMT :WA	0.16, p=0.49 NS	-0.06, p=0.79 NS	1.0					
WRMT :WI	0.34, p=0.13 NS	0.25, p=0.27 NS	0.77, p<0.01 **	1.0				
WRMT :BS	0.32, p=0.16 NS	0.14, p=0.54 NS	0.92, p<0.01 **	0.95, p<0.01 **	1.0			
NARA-3:RA	0.26, p=0.25 NS	0.25, p=0.26 NS	0.63, p<0.01 **	0.84, p<0.01 **	0.82, p<0.01 **	1.0		
NARA-3:RC	0.53, p=0.01 *	0.51, p=0.02 *	0.60, p<0.01 **	0.78, p<0.01 **	0.78, p<0.01 **	0.86, p<0.01 **	1.0	
NARA-3:RR	0.16, p=0.48 NS	0.31, p=0.18 NS	-0.09, p=0.72 NS	0.26, p=0.28 NS	0.11, p=0.65 NS	0.22, p=0.34 NS	0.11, p=0.62 NS	1.0

*significant at 0.05 ** significant at 0.01

KEY: PPVT-3 = Peabody Picture Vocabulary Test-3; CELF-3:LP = Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs; WRMT: WA, WI & BS = Woodcock Reading Mastery Tests : Word Attack, Word Identification & Basic Skills; NARA-3: RA, RC & RR = Neale Analysis of Reading Ability- 3: Reading Accuracy, Reading Comprehension & Reading Rate

Analysis of the relationship between the language scores and reading scores for the Average group showed significant Spearman's correlations between reading tests only: the *WRMT:WA* scores to the *WRMT:WI* scores (*rho* = 0.63, $p<0.05$) and both the *WRMT:WA* and *WRMT:WI* to the *NARA:RA* scores (*rho* = 0.56, $p<0.05$ and *rho* = 0.66, $p<0.05$ respectively). The *NARA:RA* correlated significantly with the *NARA:RC* scores (*rho* = 0.65, $p<0.05$) and *NARA:RR* scores (*rho* = 0.64, $p<0.05$). The results are displayed in Table 27.

TABLE 27:

Spearman's Correlations ($p \leq 0.05$) between the Receptive Language and Reading Measures for the Reading-age Matched Average Group (n=21).

Test	PPVT-3	CELF-3:LP	WRMT: WA	WRMT: WI	WRMT: BS	NARA-3:RA	NARA-3:RC	NARA-3:RR
PPVT-3	1.0							
CELF-3:LP	-0.15, p=0.51 NS	1.0						
WRMT:WA	-0.16, p=0.48 NS	-0.08, p=0.74 NS	1.0					
WRMT:WI	-0.01, p=0.97 NS	0.24, p=0.29 NS	0.62, p<0.01 **	1.0				
WRMT:BS	0.10, p=0.68 NS	-0.30, p=0.19 NS	0.80, p<0.01 **	0.91, p<0.01 **	1.0			
NARA-3:RA	-0.11, p=0.62 NS	0.01, p=0.97 NS	0.61, p<0.01 **	0.66, p<0.01 **	0.70, p<0.01 **	1.0		
NARA-3:RC	0.23, p=0.32 NS	0.05, p=0.84 NS	0.33, p=0.15 NS	0.39, p=0.08 NS	0.37, p=0.10 NS	0.62, p<0.01 **	1.0	
NARA-3:RR	0.15, p=0.52 NS	0.25, p=0.27 NS	0.21, p=0.36 NS	0.47, p=0.03 *	0.25, p=0.27 NS	0.50, p=0.02 *	0.29, p=0.21 NS	1.0

*significant at 0.05 ** significant at 0.01

KEY: PPVT-3 = Peabody Picture Vocabulary Test-3; CELF-3:LP = Clinical Evaluation of Language Fundamentals-3: Listening to Paragraphs; WRMT: WA, WI & BS = Woodcock Reading Mastery Tests : Word Attack, Word Identification & Basic Skills; NARA-3: RA, RC & RR = Neale Analysis of Reading Ability- 3: Reading Accuracy, Reading Comprehension & Reading Rate

The relationship between the RCPM measure of non-verbal intellectual ability, and the language and reading measures was explored using Spearman's correlations. The RCPM was significantly correlated with the measure of reading rate (*NARA:RR*) only (*rho* = 0.52, $p<0.05$) in the APD group and (*rho* = -0.55, $p<0.05$) in the Average group.

6.3 Relationship between Auditory Processing, Language and Reading Measures

In order to test the second stage of Hypothesis 6, the correlations between AP scores and the receptive language and reading results were examined in the APD subgroup. The results are displayed in Table 28. The measure of short-term memory, the *DS* test, was significantly correlated with both receptive vocabulary and reading comprehension. PWM, as assessed by *SR (C*), was significantly correlated with receptive vocabulary, listening comprehension and reading comprehension in the reading-age matched APD group. Given the significant correlations between the receptive language tests and reading comprehension scores reported previously, Hypothesis 6 was accepted. There were significant correlations between AP, language and reading ability for the APD subgroup in Study Two, maintaining the findings of Hypothesis 3 in Study One.

As per Study One. the *SSW(LNC)* was again significantly correlated with receptive vocabulary and also to listening comprehension. The. *PPS-C(RT)* was again correlated with *SR(C)* (*rho* = 0.467, $p<0.05$) as per Study One. Therefore the significant relationships between the *PPS-C(RT*) to PWM, and PWM to vocabulary, listening comprehension and reading comprehension were maintained in the APD subgroup in Study Two.

TABLE 28:

Spearman's Correlations (p<0.05) between the Auditory Processing and Language Measures for the Reading-age Matched APD Group (n=21).

Test	PPVT-3	CELF -3:LP	WRMT :WA	WRMT :WI	WRMT : BS	NARA -3:RA	NARA -3: RC	NARA-3:RR
SSW (RNC)	0.42, p=0.06 NS	0.20, p=0.39 NS	0.13, p=0.59 NS	-0.08, p=0.74 NS	-0.09, p=0.70 NS	0.04, p=0.88 NS	-0.02, p=0.92 NS	0.23, p=0.32 NS
SSW (LNC)	0.69, p<0.01 **	0.44, p=0.05 *	-0.15, p=0.53 NS	0.15, p=0.51 NS	0.04, p=0.87 NS	0.03, p=0.92 NS	0.14, p=0.56 NS	0.38, p=0.09 NS
SSW (RC)	0.24, p=0.29 NS	0.06, p=0.80 NS	0.03, p=0.90 NS	-0.09, p=0.71 NS	-0.03, p=0.92 NS	-0.15, p=0.52 NS	-0.09, p=0.69 NS	-0.01, p=0.96 NS
SSW (LC)	0.28, p=0.22 NS	-0.00, p=0.99 NS	0.40, p=0.07 NS	0.33, p=0.14 NS	0.36, p=0.11 NS	0.23, p=0.31 NS	0.21, p=0.36 NS	-0.15, p=0.53 NS
CS(S)	-0.17, p=0.46 NS	-0.02, p=0.93 NS	-0.13, p=0.59 NS	-0.23, p=0.33 NS	-0.15, p=0.53 NS	0.21, p=0.36 NS	0.08, p=0.72 NS	-0.08, p=0.75 NS
CS(W)	-0.40, p=0.09 NS	-0.24, p=0.30 NS	0.15, p=0.53 NS	0.15, p=0.51 NS	-0.04, p=0.87 NS	-0.16, p=0.50 NS	-0.12, p=0.62 NS	-0.25, p=0.28 NS
DS	0.60, p<0.01 **	0.35, p=0.18 NS	0.16, p=0.50 NS	0.23, p=0.31 NS	0.27, p=0.25 NS	0.21, p=0.36 NS	0.36, p=0.11 NS	0.38, p=0.09 NS
SR(B)	0.53, p=0.01 *	0.28, p=0.21 NS	0.14, p=0.53 NS	0.16, p=0.50 NS	0.20, p=0.39 NS	0.34, p=0.13 NS	0.43, p=0.05 NS	0.11, p=0.63 NS

Test	PPVT-3	CELF-3:LP	WRMT:WA	WRMT:WI	WRMT: BS	NARA-3:RA	NARA-3: RC	NARA-3:RR
SR(C)	0.69, p<0.01 **	0.46, p=0.04 *	0.14, p=0.54 NS	0.27, p=0.23 NS	0.28, p=0.23 NS	0.28, p=0.23 NS	0.54, p=0.01 *	0.30, p=0.18 NS
AFG	0.06, p=0.79 NS	-0.07, p=0.78 NS	-0.00, p=0.99 NS	-0.11, p=0.64 NS	-0.06, p=0.79 NS	-0.04, p=0.88 NS	-0.06, p=0.80 NS	-0.18, p=0.61 NS
PPS-C (R)	-0.05, p=0.82 NS	-0.06, p=0.79 NS	0.20, p=0.39 NS	0.08, p=0.72 NS	0.14, p=0.54 NS	0.05, p=0.82 NS	-0.11, p=0.65 NS	0.05, p=0.82 NS
PPS-C (RT)	0.10, p=0.66 NS	-0.03, p=0.91 NS	0.30, p=0.19 NS	0.22, p=0.33 NS	0.26, p=0.25 NS	0.09, p=0.70 NS	0.17, p=0.47 NS	0.06, p=0.80 NS
PPS-C (L)	0.04, p=0.87 NS	-0.36, p=0.11 NS	0.37, p=0.10 NS	0.14, p=0.54 NS	0.26, p=0.26 NS	0.07, p=0.76 NS	0.05, p=0.82 NS	-0.21, p=0.36 NS
PPS-C (LT)	0.04, p=0.87 NS	-0.20, p=0.39 NS	0.27, p=0.25 NS	0.26, p=0.26 NS	0.28, p=0.21 NS	0.17, p=0.46 NS	0.23, p=0.31 NS	-0.19, p=0.41 NS
RGDT	0.42, p=0.06 NS	0.21, p=0.37 NS	-0.09, p=0.69 NS	0.00, p=0.99 NS	-0.04, p=0.86 NS	-0.23, p=0.31 NS	0.01, p=0.98 NS	0.02, p=0.92 NS

*significant at 0.05 ** significant at 0.01

KEY: SSW = Staggered Spondaic Word test; (RNC) = Right Non-competing condition, (LNC) = Left non-competing condition, (RC) = Right competing condition, (LC) = Left competing condition; CS = Competing Sentences test; (S) = Strong, (W) = Weak; DS = Digit Span test; SR = Sentence Recall test : (B) = Basal, (C) = Ceiling; AFG = Auditory Figure Ground; PPS-C = Pitch Pattern Perception test – non-speech test, (L) = LeftEar, (R) = Right Ear, (LT) = Left Total, (RT) = Right Total; RGDT = Random Gap Detection Test – non-speech test

6.4 Descriptive Error Analysis

Reading errors (798 in total) on the *NARA-3* were analysed in terms of whether the error could be classified as ‘meaning retained’ or ‘meaning lost’, using the *RAP* analysis. There was no significant difference in the total errors or the number of errors that lost or retained meaning between the APD group and the reading-age matched

Average group. The APD group are therefore, making a similar number of errors as the group of average readers who are significantly younger. Descriptive results are presented in Table 29.

TABLE 29:
Error Totals for the APD Group compared to the Average Group.

Error Category	APD group total (n=21)	Mean (SD)	Percentage	Average group total (n=21)	Mean (SD)	Percentage
Meaning Lost	289	13.8 (7.4)	79%	335	15.5 (10.6)	78%
Meaning Retained	77	3.67 (2.89)	21%	97	4.7 (3.30)	22%
Total Errors	366	17.4 (9.6)	100%	432	20.6 (12.4)	100%

Further analysis of the seven *RAP* error categories indicated differences in the profile that characterised each group. The APD group made a greater number of substitutions and fewer recasting and decoding errors. The results are displayed in Table 30.

TABLE 30:
Descriptive Analysis of Error Categories compared by Group.

Error Category	APD group (n=21)	Mean	Average group (n=21)	Mean
Visual	5	0.24	6	0.29
Recast	12	0.57	32	1.50
Deletions	35	1.60	32	1.50
Additions	33	1.57	31	1.48
Substitutions	150	7.14	115	5.48
Decoding	122	5.81	203	9.60
Other	9	0.43	13	0.62

A breakdown of the individual error types within the error categories identified four error types of interest. Two substitution error types (word shape and meaning substitutions) occurred more frequently in the APD group whereas recasts and decoding error types occurred more frequently in the Average group. All other error types were represented equally. The distribution of the four selected error types are displayed in Table 31.

TABLE 31:
Descriptive Analysis of Selected Error Types for the APD Group compared to the Average Group.

	APD group (n=21) total	APD group mean (SD)	Percentage of total errors	Average group (n=21) total	Average group mean (SD)	Percentage of total errors
Substitution –Word Shape	84	4.0 (2.02)	23%	72	3.4 (2.58)	16%
Substitution-Meaning	29	1.4 (1.32)	8%	9	0.4 (.68)	2%
Recast-Meaning	12	0.6 (1.08)	3%	32	1.5 (1.44)	7%
Decoding	122	5.8 (5.47)	33%	203	9.6 (8.15)	47%

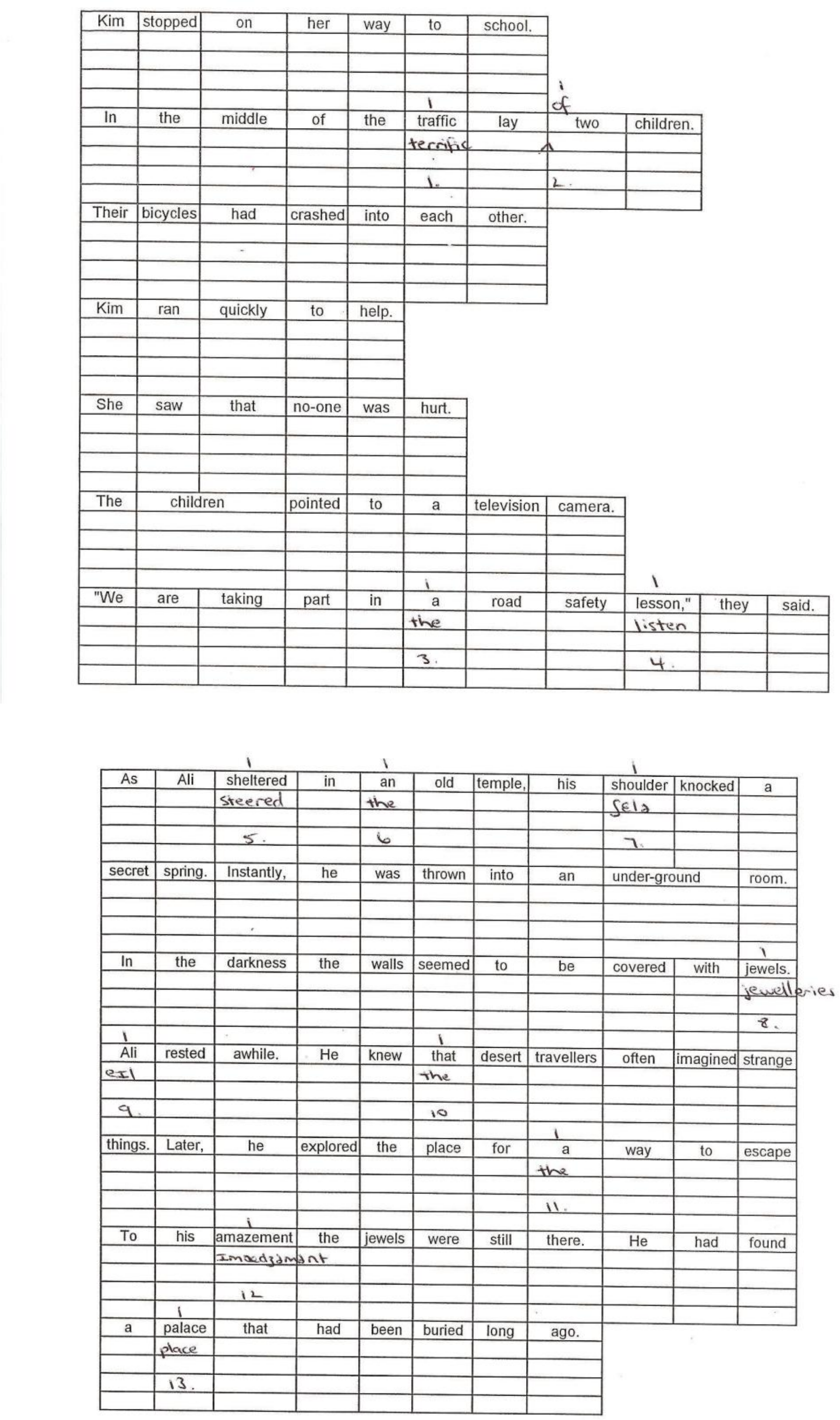
Hypothesis 7 stating that the reading error analysis will show differences in the reading error pattens of the APD group compared to the Average group was accepted.

Table 32 shows the success rates of self-correction for both the APD and Average groups. The APD group is more successful at self-correcting substitutions but less successful at self-correcting decoding and recasting errors than the Average group.

TABLE 32:
Success Rates of Self-corrections on Selected Error Types by Group.

Error type	Self-corrections: APD group (n=21)	Total errors	% errors self-corrected	Self-corrections Average group (n=21)	Total errors	% errors self-corrected
Substitutions: word shape	15	84	18%	6	72	8%
Substitutions: meaning	7	29	24%	0	9	0%
Recasting	11	12	92%	32	32	100%
Decoding	12	122	9%	32	203	16%

Appendices T and U provide a full *RAP* analysis for the following passages displayed in Figures 9 and 10, read by participants from a reading-age matched pair i.e. one from the APD group and one from the Average group. The raw data provide an example of the reading error patterns exhibited by each group.



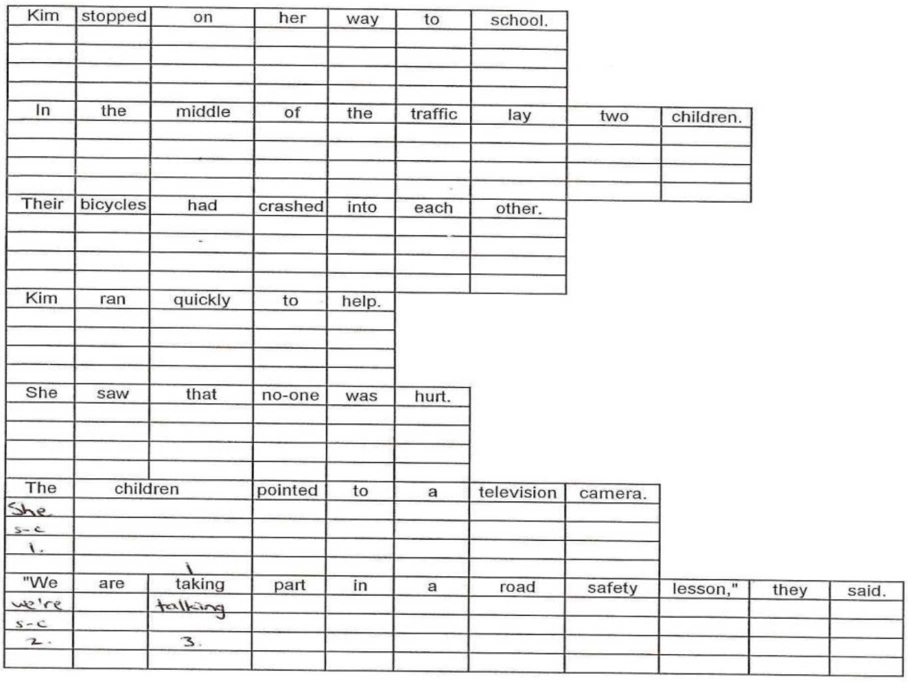
Kim	stopped	on	her	way	to	school.		
					1		1 of	
In	the	middle	of	the	traffic	lay	two	children.
					terrific	^		
					1.		2.	
Their	bicycles	had	crashed	into	each	other.		
Kim	ran	quickly	to	help.				
She	saw	that	no-one	was	hurt.			
The	children	pointed	to	a	television	camera.		

					1			1		
"We	are	taking	part	in	a	road	safety	lesson,"	they	said.
					the			listen		
					3.			4.		

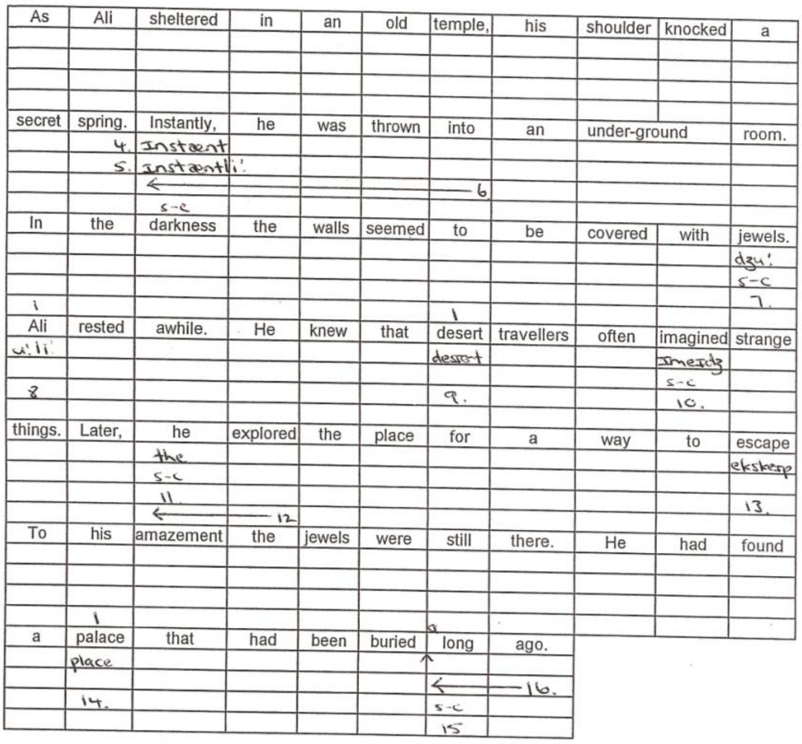
		1		1				1		
As	Ali	sheltered	in	an	old	temple,	his	shoulder	knocked	a
		steered		the				Sela		
		5.		6				7.		
secret	spring.	Instantly,	he	was	thrown	into	an	under-ground		room.
										1
In	the	darkness	the	walls	seemed	to	be	covered	with	jewels.
										jewelleries
										8.
1					1					
Ali	rested	awhile.	He	knew	that	desert	travellers	often	imagined	strange
eɪl					the					
9.					10					
							1			
things.	Later,	he	explored	the	place	for	a	way	to	escape
							the			
							11.			
		1								
To	his	amazement	the	jewels	were	still	there.	He	had	found
		ɪmædʒəmənt								
		12								
	1									
a	palace	that	had	been	buried	long	ago.			
	place									
	13.									

FIGURE 9: Two paragraphs of the *NARA-3* as read by a participant in the APD group.

N.B. The stroke '1' marked above an error denotes NARA-3 error scoring. The numerals below an error denote RAP analysis scoring.



Kim	stopped	on	her	way	to	school.				
In	the	middle	of	the	traffic	lay	two	children.		
Their	bicycles	had	crashed	into	each	other.				
Kim	ran	quickly	to	help.						
She	saw	that	no-one	was	hurt.					
The	children		pointed	to	a	television	camera.			
She										
s-c										
1.										
		1								
"We	are	taking	part	in	a	road	safety	lesson,"	they	said.
we're		talking								
s-c										
2.		3.								



As	Ali	sheltered	in	an	old	temple,	his	shoulder	knocked	a
secret	spring.	Instantly,	he	was	thrown	into	an	under-ground		room.
	4.	Instaent								
	5.	instaentli:								
		←				6				
		s-c								
In	the	darkness	the	walls	seemed	to	be	covered	with	jewels.
										dʒu:
										s-c
1						1				7.
Ali	rested	awhile.	He	knew	that	desert	travellers	often	imagined	strange
u:li:						dessert			Imeɪdʒ	
									s-c	
8						9.			10.	
things.	Later,	he	explored	the	place	for	a	way	to	escape
		the								ekskeɪp
		s-c								
		11.								13.
		←	12							
To	his	amazement	the	jewels	were	still	there.	He	had	found
	1					a				
a	palace	that	had	been	buried	long	ago.			
	place					←	16.			
	14.					s-c				
						15				

FIGURE 10: Two paragraphs of the *NARA-3* as read by a participant in the Average group.
N.B. The stroke '1' marked above an error denotes NARA-3 error scoring. The numerals below an error denote *RAP* analysis scoring.

6.4 Summary of Study Two

As reported in the Method, the APD group and Average group in Study Two were matched for reading accuracy raw scores and age equivalency on the *NARA: Reading Accuracy* measure. The chronological age of the two groups was significantly different with the Average group being significantly younger. The scores on the RCPM measure of non-verbal intellectual ability was also significantly different, but the mean scores fell within the average range for both groups.

The APD group performed significantly poorer on *standard scores* for both receptive language and all reading tests, with the exception of the NARA measure of reading rate. This strongly indicates that the APD group are experiencing significant receptive language and reading difficulties.

Again, strong correlations were found between PWM ability on the *Sentence Recall (C)* and both receptive language tests, the *PPVT-3* and *CELF-3:LP*, and the *Neale Analysis of Reading Ability: Reading Comprehension (NARA:RC)* scores, but not to the reading accuracy (*NARA:RA*) or the reading rate (*NARA:RR*) scores for the APD group. The findings support an interaction between PWM, receptive language and reading *comprehension*. There were no significant correlations between auditory processing ability and word reading skills. The word reading tests, the *WRMT: Word Attack* and the *WRMT: Word Identification* scores correlated significantly with the *NARA* measure of reading accuracy in both the APD and Average groups.

The descriptive error analysis showed that the total number of errors were similar for the APD group and the significantly younger average group. About the same number of errors lost meaning and retained meaning also. This shows that APD readers are making the same numbers of errors overall as reading –age matched younger readers. Analysis of the pattern of reading errors yielded some interesting results. In particular, the APD readers made more substitution errors based on word shape or meaning but made fewer decoding errors or recasts.

CHAPTER SEVEN

Discussion

7.0 Summary of Main Findings

7.0.1 Main Findings of Study One

Study One compared the auditory processing, receptive language and reading performance of the APD group and the NAPD group. The relationship between the degree of AP deficits to receptive language and reading performance was analysed. Additional aspects of AP performance, receptive language and reading ability were also examined. Finally, a descriptive analysis of the pattern of reading errors for the two groups was undertaken.

It was important to firstly establish the differentiation of AP performance between the APD and NAPD groups, based on performance on the FUSAPB. The significantly poorer performance on the dichotic listening tests, the *Staggered Spondaic Words (SSW)* test and *Competing Sentences (CS),* test suggests the presence of interhemispheric transfer deficits and possibly auditory discrimination, linguistic and or attention deficits in the APD group compared to the NAPD group. Of all tests in this study, performance on the *SSW(Left Competing)* condition was the most discriminating variable of APD vs. NAPD group membership. Poor performance on the left competing condition indicates poor interhemispheric transfer of linguistic information via the corpus callosum, as explained in the *Method* section of this thesis.

The significantly poorer performance on the *Sentence Recall:Basal (SR-B)* and *Sentence Recall:Ceiling (SR-C)* test by the APD group compared to the

NAPD group suggests the presence of PWM deficits in the APD group. There was no significant difference on performance on the digit span test between the APD and NAPD groups, with mean standard scores falling below one standard deviation for both groups. The lack of a significant difference on the digit span test is discussed in this chapter in 7.1.2.

There were no significant differences between the performance of the APD group on the *PPVT-3* test of receptive vocabulary or the *CELF:LP* test of listening comprehension compared to the NAPD group. The mean standard scores for both tests were below the mean for chronological age in the APD group and also for the *PPVT-3* in the NAPD group. These findings are discussed in sections 7.3 and 7.4.

Mean standard scores on reading performance in both the APD and NAPD groups were not significantly different between the two groups but were below the mean for chronological age, with reading accuracy standard scores being the lowest. The hypothesis that students in the APD group would have significantly greater reading difficulty than those students in the NAPD reference group was rejected.

At this stage of the analysis the receptive language and reading abilities of the APD group and NAPD group were not different, with only AP performance being significantly different. Therefore, it might be concluded that AP skills and/or deficits were unrelated to receptive language or reading ability. However, this would not represent the full picture.

The overall auditory processing severity (APS) score was moderately correlated with *PPVT-3* performance, but the AP-DL (derived from the standard scores on the dichotic tasks *Staggered Spondaic Words* test and the *Competing*

Sentences test) was *not* significantly correlated with *PPVT-3* performance in the APD group. In contrast the AP-STM performance (derived from the *Digit Span* and *Sentence Recall* tasks i.e. memory component) was strongly correlated with *PPVT-3* performance. This is an important finding that suggests a relationship between memory component of AP performance and vocabulary performance. This finding agrees with previous research supporting a position that PWM underpins vocabulary acquisition (Gathercole et al., 1992; Wagner, Torgesen & Rashotte, 1994b; Metsala, 1999). Gathercole et al. (1992) stated that a strong auditory trace is necessary for a vocabulary item to be linked to its semantic referent. Baddeley et al. (1998) proposes that this auditory trace is a function of the integrity of the auditory information in the phonological store, holding the phonological form in PWM.

The APS and AP-STM scores were weakly correlated with *CELF-3:LP* performance in the combined APD + NAPD group. The AP-DL score was *not* correlated with *CELF-3:LP* performance in either the combined group or the APD group. The correlation with memory, but not dichotic listening indicates a relationship between listening comprehension and the memory component of AP performance.

Significant correlation of the AP-DL severity score with PWM performance on the *SR* test in both the APD group and the combined APD + NAPD group suggests a relationship between auditory dysfunction and PWM ability. This was further supported by a significant correlation of the *SSW: Left Competing* condition with *Sentence Recall* performance in the combined group.

In the APD group *SR-C* performance correlated strongly with the *PPVT-3* scores and moderately with the *CELF-3:LP* and *NARA-3:RC* scores. Vocabulary performance was strongly correlated with listening comprehension and reading comprehension in the APD group in this study whereas listening comprehension and reading comprehension were moderately correlated with each other. The results indicate significant relationships between PWM, vocabulary, listening comprehension and reading comprehension.

Two non-speech auditory processing tests, the *Random Gap Detection Test (RGDT)* and the *Pitch Pattern Sequence-Child* (*PPS-C*) test were included in the study. There was no significant difference between the performance of the APD and NAPD groups on these two non-speech tests. However, the performance on the *RGDT* (and not the *PPS-C*) was three standard deviations below the expected mean for both groups. Further, the results indicated a relationship between performance on the other non-speech test, the *PPS-C,* and phonological working memory in the APD group. Specifically, the non-speech skills tested on the *PPS-C* are temporal order judgement and frequency discrimination. Deficits in these skills have been previously found in poor readers (Tallal, 1980; Witton et al., 1998; Heath et al., 1999; Talcott et al., 1999; Cestnick & Jerger, 2000; Heiervang, Stevenson & Hugdahl, 2002; Fischer & Hartnegg, 2004). The scores on the *PPS-C* correlated with the *SR(B)* and *SR(C)* but not with vocabulary nor with comprehension performance. Scores on the *PPS-C(RT)* and *PPS-C(LT)* also correlated significantly with the word reading tests, further discussed in 7.1.3.

Multiple regression analyses attributed word identification as the strongest contributing variable to reading accuracy and both word identification and sentence recall as the strongest contributing variables to reading comprehension, both discussed further in 7.5.3 and 7.5.4.

Reading errors made by the participants in the APD group were less likely to retain the intended meaning of the text, compared to the NAPD group in Study One. For example, ‘on the backs of sheep’ retains the meaning of ‘on the back of sheep’ whereas ‘he had found a place’ does not retain the meaning of ‘he had found a palace’. The pattern of reading errors across the two groups was similar, with the APD group making slightly fewer visual errors, deletion errors, recasts and decoding errors.

7.0.2 Main Findings of Study Two

Study Two compared the receptive language and reading performance of the APD group and the Average reader group, matched for reading accuracy scores on the *NARA: Reading Accuracy* measure. The participants in the Average reader group were significantly younger than the participants in the APD group, with a difference in mean age of 13 months. Relationships between receptive language and reading ability in the APD group were also examined. A descriptive analysis of the pattern of reading errors for the two groups was undertaken.

The APD group had significantly poorer receptive language abilities and significantly poorer reading abilities than the Average group. The APD group was found to exhibit significantly poorer receptive vocabulary performance on the *PPVT-3* than the reading-age matched Average group. The APD group in Study Two was a subgroup of the APD participants in Study One. Once again, vocabulary performance was strongly correlated with listening comprehension and reading comprehension in the APD group in Study Two. The APD subgroup was found to be experiencing significantly greater difficulty with performance on the *CELF-3:LP* test of listening comprehension compared to the reading-age matched Average group.

The standard scores on all tests of reading ability (Word Attack, Word identification, Reading Accuracy and Reading Comprehension) were significantly poorer for the APD group compared to the Average group, with the exception of reading rate. In addition, the *SR* measure of PWM was strongly correlated with reading comprehension in the APD group. This implicates PWM ability as a limiting factor in reading comprehension performance.

The APD group made as many errors that lost the intended meaning of the text as the Average reader group. Analysis of error types in the APD group showed a greater number of whole word substitutions of meaning and word shape and fewer recasting and decoding errors compared to the Average group.

7.1 Auditory Processing & Severity

7.1.1 Dichotic Tests

Performance on the *Competing Sentences (CS)* dichotic listening task requires separation of auditory input and also depends upon linguistic processing and allocation of *selected* attention to the target ear by the central executive (Lamm & Epstein, 1997). Performance on the *Staggered Spondaic Words (SSW)* dichotic listening task requires integration of auditory input and also depends on linguistic processing but requires *divided* attention to the information received by both ears. Both types of dichotic listening tasks are also evaluating the integrity of the neural pathways to process auditory information across time. Involvement at the cortical level is reflected in the ear score contralateral to the dominant hemisphere for language processing, usually the score for the right ear. Corpus callosum involvement will be reflected in the ear score that is ipsilateral to the dominant hemisphere for language processing, usually the score for the left ear. Particular difficulty in the left competing condition is an indicator of inefficient interhemispheric transfer of information via the corpus callosum (Medwetsky, 2002b), especially when right ear performance is greater than would be expected as a normal right ear advantage, as explained in the Method.

The AP-DL was derived from the *SSW* and *CS* tests and was significantly poorer for the APD group compared to the NAPD group. The AP-DL also correlated significantly with the PWM measure, the *SR(C)* test. The *SSW(RC),* considered to be associated with language processing, correlated moderately significantly with PWM, *PPS-C(RT)* and vocabulary scores, as reported under discriminant analysis in the Results chapter. In addition, the *SSW(LC)* test, testing interhemispheric transfer of information, was the most discriminating test of APD group membership. Performance on the *SSW(LC)* was moderately correlated with PWM performance in the combined APD+NAPD group. These findings suggest that interhemispheric transfer deficits may contribute to PWM performance.

The dichotic listening tests (the *SSW* competing conditions and the *CS* test) did not correlate significantly with any of the reading tests, with the exception of the *CS (W)* to reading rate in the APD group. The weaker ear on the *CS* test is usually the left ear, due to the right ear advantage. When dichotic tests were correlated with the language tests, again only the *CS(W)* correlated significantly with the vocabulary test. This suggests that poor interhemispheric transfer of auditory information and/or selective attention may influence language performance.

An unexpected result was the significant correlation of the *SSW* non-competing condition scores to tests of PWM and vocabulary, given a lack of significant correlation between the *SSW competing* condition scores to these variables. There are at least three possible explanations of these findings:

a. The participants were unable to perform rapid speech perception prior to the onset of the competing condition due to underspecified phonological representations in LTM;
b. The participants did not have an existing phonological representation for culturally specific, possibly dated test items e.g. corn-bread, wash-tub;
c. Performance was diminished by poor top-down processes such as phonetic encoding i.e. difficulty making a decision about what has been heard.

Performance on the *SSW(RNC)* and *SSW(LNC)* was significantly poorer for the APD group than the NAPD group, with error rates of up to 55% (refer Table 3 in the Method). The moderate correlations of the *SSW* results in both the Left and Right Ear non-competing conditions to *PPVT-3* performance lend further weight to the argument that words in isolation (i.e. without visual or contextual cues) are not able to be rapidly encoded, as per the first explanation above. Carey and Bartlett (1978) stated that efficient vocabulary acquisition requires the rapid formation of phonological 'maps' of the new word i.e. fast mapping. Low performance in the non-competing conditions suggests poor fast mapping of auditory input to phonological representations in long-term memory. It seems likely that poor fast mapping could also account for the moderate correlations between the non-competing conditions on the *SSW* to the *SR(C)* and *PPVT-3* scores in this study. It may be that low performance on the *SSW* non-competing conditions could be used as an alert to potential PWM and vocabulary difficulties. The second explanation above would be expected to affect the APD and NAPD groups equally, and given there was no significant difference in the vocabulary performance between the APD and NAPD groups it is an unlikely explanation. It is not possible to draw conclusions regarding the third explanation above from the available data, except to say that the APD group had average non-verbal intellectual abilities and therefore the reasoning and categorization abilities required for phonetic encoding would be expected to be intact. Phonetic coding performance, however, *may* be affected by input processing, resulting in uncertainty regarding what has been heard. That is, the APD group have average reasoning and categorization capabilities but cannot apply these when the information in the phonological store is degraded.

7.1.2 Digit Span and Sentence Recall Tests

It has been proposed that short-term memory (STM) tasks which do not require working memory, such as tests of digit span or word recall, are under the domain of attention (Cowan, 2001). Of all the tests in the FUSAPB, the *Digit Span* test was the only test in which the standard scores were not significantly different between the APD and NAPD groups, though both mean standard scores were below the average range for this age group. The scores on the *DS* test and *RGDT* test were moderately correlated with each other in the APD group, but not in the NAPD group. As the DS is considered to be a test of short-term auditory memory *and/or* auditory attention, but the *RGDT* is *not* considered a test of short-term memory, the correlation in the APD group suggests that a common factor (such as attention) may be affecting performance on both tests. Alternatively, poor performance on the *DS* and *RGDT* tests in the APD group may occur due to input processing difficulties (affecting the phonological store) while poor performance in the NAPD group may occur for another reason such as fluctuating attention, resulting in uncorrelated scores.

At first, the low performance on the *DS, RGDT* and reading accuracy tests in both the APD and NAPD groups may appear to suggest a relationship between short-term memory, temporal resolution and reading ability, However, unlike PWM performance on the *SR* test, the performance on both the *DS* and *RGDT* tests was not correlated with receptive language or reading performance. This is in agreement with the findings of previous research (De Beni et al., 1998; De Beni & Palladino, 2000; Sharma et al., 2006).

In the *SR* task, more linguistic context is provided than during a single word repetition task. Individuals with PWM limitations can be successful at repeating more words in a meaningful string compared to unrelated words, but only to a point. Once the capacity of the short-term phonological store has been exceeded, active PWM processes assist retention. For instance, the information may be ‘chunked’ to assist rehearsal or information stored in long-term memory is retrieved in order to process, condense and transfer the information into LTM, ready to receive the next piece of input. If the available information in the short-term phonological store is unreliable, PWM performance breaks down, corresponding to below average ability for chronological age as observed in the

APD population. Beyond this point, words may be omitted, jumbled or converted to a condensed version. It is as if the spoken input continues to 'cannon' into the auditory system, but the component parts are no longer able to be processed or retained verbatim. The skills mentioned above, namely rapid temporal processing, temporal order judgement and frequency discrimination may be at least partly responsible for this breakdown, particularly in combination.

7.1.3 Non-speech Tests

There was no significant difference between performance on the non-speech tests, the *PPS-C* and *RGDT*, between the APD and NAPD groups in Study One. However, performance on the *RGDT* was well below the average range on normative data for both groups.

While the normal listener is able to accommodate different speakers, the further spoken sounds or words deviate from the culturally conventional phonological representation, the more difficult it will be to recognize and match these with existing semantic representations, as in the case of an unfamiliar accent (McQueen, 2007). Information about pitch, duration, stress and acoustic contours assist word recognition and word boundary identification in continuous speech. It is plausible, therefore, that AP skills such as rapid temporal processing, temporal order judgment and frequency discrimination will have an impact on phonological discrimination, phonological comparison with previous stimuli and the phonological encoding necessary for adequate short-term memory, phonological working memory and ultimately access to long-term memory for listening and reading comprehension.

In addition to moderate correlations to PWM already discussed, *PPS-C* performance was correlated with performance on the *WRMT:WA & WI* subtests. The correlations between left ear performance on the *PPS-C(L)* and *PPS-C(LT)* with word reading were strong. The scoring on the *PPS-C* allows for the effects of temporal ordering to be removed under the Right Total *(RT)* and Left Total *(LT*) scores. Multiple regression analysis attributed a stronger contribution of *PPS-C(LT)* scores to word identification than *PPS-C(L)* scores and a stronger contribution of *PPS-C(RT)* scores to reading accuracy than *PPS-C(R)* scores. It could be said that the frequency discrimination aspect of *PPS-C* performance makes a greater contribution to word identification ability than the temporal ordering aspect of this test.

The above finding suggests that frequency discrimination or PWM for acoustic contours may exert some influence on acquisition of both sound-to-letter and spoken word-to-written word correspondence (or vice-versa). Alternatively, as proposed by Bishop (2002), it may be that AP deficits, such as poor frequency discrimination, and PWM deficits are additive risk factors for phonological processing and literacy outcomes. In contrast to the *PPS-C* results for frequency discrimination, there were no significant correlations between the *RGDT* test of temporal resolution and reading performance.

Temporal resolution skills were poor in the APD population yet did not correlate with either receptive language or reading performance whereas frequency discrimination and/or temporal ordering performance were correlated with word reading ability. This suggests that information about pitch (and possibly, sequence) exerts a greater influence on reading outcomes in the APD group than rapid temporal resolution. As previously discussed, perhaps temporal resolution ability on the *RGDT* is affected by other variables, such as attention, having a different impact on reading performance, not investigated in this study.

7.1.4 Severity

The AP-DL severity score was significantly correlated with PWM in the APD group and receptive vocabulary in the combined APD + NAPD group. This suggests that auditory dysfunction is related to, and possibly contributes to both PWM performance and language development. The overall APS (AP severity score) and the AP-STM severity scores were also significantly correlated with vocabulary in both the APD group and the combined APD+NAPD group. The correlations with the AP-STM scores were strong in both instances, reinforcing the relationship between PWM and vocabulary development. Again, this relates to the second area for vocabulary development described by Brackenbury and Pye (2005) i.e. the importance of the ability to hold phonological information while searching for associated information in long-term memory. The findings supplement the longitudinal findings of Wagner et al (1994) who found that the developmental rate of PWM was comparable to the developmental rate of vocabulary acquisition in 5 to 7 year olds.

The APS and AP-STM severity scores were also weakly to moderately correlated with the *CELF-3:LP* scores in the combined APD+NAPD group but not the APD group. One possible explanation for this finding is that the misclassified NAPD participants who were experiencing difficulty on one of the dichotic listening tasks *and* showed poorer listening comprehension are included in the combined group, allowing the significant relationship to show.

Speculatively, it may be that listening comprehension is more affected when *both* PWM and dichotic listening skills are weak.

There were no significant correlations between AP severity and the reading measures. This reflects the multifactorial nature of reading performance. It would seem that the severity of AP difficulty, and in particular PWM difficulty, is most relevant for vocabulary development. Overall, the finding of a relationship between the degree of AP deficits to receptive language but not to reading concurs with the findings of Tallal and Stark (1982) and Heath (1999) who found auditory deficits in only those poor readers with concomitant language difficulties.

7.2 Phonological Working Memory

The performance of the APD group was significantly poorer on the SR(C), a measure of phonological working memory (PWM). Low performance on the *SR* test of PWM was significantly correlated with *PPVT-3*, *CELF-3:LP* and *NARA:RC* standard scores in this study. PWM performance was correlated with all AP severity measures: APS, AP-DL and AP-STM and the non-speech *PPS-C(RT)* performance. The measure of PWM is a component of both the APS and AP-STM scores and so significant correlations would be expected. However, correlation of the AP-DL score with the *SR(C)* score suggests that auditory dysfunction contributes to PWM performance. In addition, *PPS-C: (R)* and *(RT)* measures, correlated with *SR(C)* scores. In the combined APD+NAPD group both the *SSW (LC)* and *SSW (RC)* correlated significantly with the SR(C) scores. In sum, the results suggest the possibility of auditory-linguistic integration deficits, as described in 3.4.2.2.: a relationship between the interhemispheric transfer of linguistic information on *SSW (LC)* plus frequency discrimination on the *PPS(RT)* affecting PWM. Speculatively, phonological working memory may be exerting a greater effect on listening and reading comprehension than linguistic ability.

Poor readers and children with language impairments have been found to consistently perform poorly on measures of PWM, as described in the literature review. Some interesting conclusions have been drawn from recent studies which have shown phonological working memory to be a better predictor of literacy outcomes than IQ (Alloway, 2009; Alloway et al., 2009). In combination, these results indicate that PWM ability plays an important role in vocabulary performance and both listening and reading comprehension.

To refresh, PWM is composed of a short-term phonological store, the phonological loop and the episodic buffer (Baddeley, 2000). Individuals with language impairment have been found to have deficits in phonological loop function, the rehearsal component of PWM. Weak rehearsal leads to loss (or fading) of the early stages of auditory input during a PWM task. The consequence is a recency effect where only the most recent input is recalled. Of course, this is only a difficulty when an overall reduced amount of information is able to be recalled. In relation to the phonological store component, Jones, Macken and Nicholls (2004) concluded that the better auditory perception is, the better PWM ability will be with consequent effects on language processing and storage. Further, Jones et al. (2004) proposed that the relationship is reciprocal i.e. the better language skills are, the more efficient PWM will be. Neurologically, the frontal area of auditory cortex (Heschl’s gyrus) within the temporal lobe is considered responsible for recognition of the auditory stimulus and for short-term phonological memory (Martin, 1997). Frequency discrimination occurs in the middle temporal gyrus while temporal processing occurs in the superior temporal gyrus and the insula between the temporal and frontal lobes. Linguistic processing of speech input is largely performed in the parietal areas. The greater the integrity of the information received by the parietal from the temporal areas, the faster perception and linguistic processing can occur prior to phonological working memory.

The correlation of the *PPS-C(RT)* performance to *SR(C)* performance in both studies also suggests a relationship between frequency discrimination, temporal order judgement and PWM that requires further exploration. The indicators are that PWM is potentially undermined by poor processing of frequency and/or acoustic contours of sounds, words and sentences. The results are in accordance with the recent research showing that individuals with APD and reading difficulties (aged 8 to 12 years) have particular difficulty with frequency discrimination as measured on the Frequency Pattern Test (Sharma et al., 2009). Given that:

i. the *PPS* test was the most sensitive test of AP functioning of seven tests reviewed (Musiek et al., 1982);
ii. temporal order judgement and frequency discrimination have been found to be correlated (Heath et al., 1999; Fischer & Hartnegg, 2004) and;
iii. formant information and voice onset/offset information is considered to be critically important for speech perception (Abrams & Kraus, 2009), it would seem that there is good evidence that input processing in the presence of AP deficits may undermine the establishment of the stable phonological representations necessary for efficient PWM.

While the evidence for the effect of AP deficits upon PWM performance is mounting, the findings cannot be considered definitive of causation. Alternative views must also be considered. For instance, Bishop's (2001) findings suggested that it is the co-morbidity of AP and PWM deficits that creates a risk factor for language impairment, rather than a causative relationship. It is important that both avenues of enquiry be thoroughly explored in future research.

Early PWM performance, based on non-word repetition ability, has previously been found to predict syntactic and semantic ability in later years (Metsala, 1999) which concurs with the present findings. Recent work by Archibald and Joanisse (2009) demonstrated that the sensitivity of a screening measure of PWM (sentence recall and nonword repetition) used for the detection of language deficits was 84% for nonword repetition, and 90% for sentence recall alone. In addition, the specificity of sentence recall as a marker of language impairment was 85%. Further research found that when weak PWM abilities were associated with naming difficulties this was an indicator of dyslexic tendencies (Archibald & Joanisse, 2009) in some individuals. In summary, PWM performance is emerging strongly as an indicator and possibly predictor of language performance.

7.3 Vocabulary

There was no significant difference between the performance of the APD group compared to the NAPD group on the *PPVT-3* test of receptive vocabulary in Study One. However, the APD group was found to exhibit significantly poorer receptive vocabulary performance on the *PPVT-3* than the reading-age matched Average group in Study Two.

The key components of vocabulary acquisition identified by Brackenbury and Pye (2005) were 1) perception of auditory input; 2) the ability to hold auditory input and 3) extraction of meaning based on the former two factors. This study provides evidence that the APD group does experience difficulties with perception of auditory input as demonstrated by significantly poorer performance on the diagnostic FUSAPB procedure. This study also provides evidence that the APD group does experience difficulties with the ability to hold auditory input, demonstrated by significantly poorer PWM ability and thirdly the APD group does experience difficulty with the extraction of meaning as demonstrated by significantly poorer listening comprehension and reading comprehension ability. The combined effect of these difficulties provides support for a relationship between AP performance and vocabulary acquisition.

Poorer performance on comprehension tasks cannot be attributed to below average intelligence in the APD group because average non-verbal intellectual ability was an inclusion criterion for the study. However, the mean non-verbal intellectual ability score was significantly lower for the APD group compared to the Average group and therefore cannot be dismissed altogether.

Given the strong correlations between the *Sentence Recall* tests and receptive vocabulary performance, this finding reflects a relationship between phonological working memory and vocabulary knowledge. This finding extends the view previously put forward by Gathercole and Baddeley (1993) that phonological short-term memory underpins vocabulary *acquisition*. The objective of vocabulary acquisition is information storage. Auditory or print input must be processed in phonological working memory and then stored in long-term memory for later retrieval. A phonological representation of the word and a semantic representation of the concept are held in semantic memory. Retrieval of associated existing information from long-term memory into PWM via the episodic buffer also assists the storage task (Hamilton & Martin, 2005).

It was found that verb knowledge, as tested in the *PPVT-3*, was poorer in the APD group compared to the NAPD group. Verbs hold key information for language comprehension, but are less imageable than nouns or descriptors, have changing morphology (e.g. eat, eats, eating, ate) increasing the complexity of the phonological matching process and they may have one or more agents (transitive verbs) or no object (intransitive verbs) making them more abstract and complex (Ferretti, 2001). O’Hara and Johnston (1997) were able to show that difficulties with verb learning in children with language impairment were due to difficulties with processing and not syntax. For instance, low verb acquisition may reflect the reduced ability to make use of the visuo-spatial sketchpad in working memory to compensate for weak phonological memory and representations. Brackenbury and Pye (2005) concluded that children with language impairment had difficulty maintaining phonological forms in short-term memory and matching phonological forms to semantics at the core of their difficulties with verb acquisition.

Another consideration is that vocabulary acquisition may be more phonologically dependent in the early years and then become more semantically dependent later on (Snowling, 2000). The suggestion is that pre-literate vocabulary development is phonologically dependent on auditory input but as reasoning and literacy develop, vocabulary development may become more dependent on extraction of meaning. This may explain why some individuals with APD who struggle initially can become good readers in the long-term. The implication is that linguistic potential may be normal in the APD population, but is compromised when learning is dependent on auditory input.

There is evidence to suggest that PWM ability may become less important for vocabulary acquisition after 4 to 5 years of age (Gathercole & Baddeley, 1993) as the role of reading experience increases in its importance. This supports numerous studies that have concluded that reading and vocabulary development enjoy a reciprocal relationship. A low vocabulary may be enriched as reading skills develop, allowing the Matthew effect to be engaged, as described in the literature review (refer to section 2.6.2.3) (Stanovich, 1986). In principle, LSR with concomitant APD should be able to add new word meanings to semantic storage from print input during the reading task. Auditory input is absent and the visual aspects of print should be perceived accurately. Print remains a stable reference point, allowing the reader to control the rate of processing while semantic searching is undertaken prior to storage. This study has found that there are impediments to reading success in the APD group aged 8 to 11 years, affecting both accuracy and comprehension. If vocabulary is low when entering the period of early reading instruction it will impede reading acquisition, reducing the opportunity for reciprocal benefits upon vocabulary development. It is therefore critical for individuals with APD to be assisted towards reading competency once reading instruction has commenced in order to avoid the compounding delay upon vocabulary development from reduced reading experience. Print input can only provide a good source of linguistic input once reading is successful. As shown in this study, both vocabulary and reading ability were significantly poorer in the APD group compared to the Average group. Therefore, LSR in the APD group are unlikely to be able to take full advantage of the benefits of print input upon vocabulary development.

7.4 Listening Comprehension

The significant difference between the APD group and the Average group on the *CELF-3:Listening to Paragraphs* subtest in this study supports the contention that inefficient speech perception, impaired PWM and impaired vocabulary performance may have an impact on listening comprehension performance. The *SR(C)* correlated moderately with the listening comprehension score while *PPVT-3* scores correlated strongly with listening comprehension in the APD group in both studies. There is now good behavioural and neurophysiological evidence of AP deficits in a number of children with language impairment (Wright et al., 1997; Bishop & McArthur, 2005; Wible et al., 2005). This was not unexpected: Normal binaural hearing allows spatial and spectral filtering of auditory input in order to determine the location of the input, separate the target speaker from ambient noise and discriminate speech (Eggermont, 2001). The evidence to date suggests that the latter function relies upon accurate information regarding timing aspects (especially voice onset/offset and processing rapid changes) and frequency information (especially acoustic contours within formants, across words and utterances) (Jones et al., 2004; Wible et al., 2005; Sharma et al., 2006; Abrams & Kraus, 2009; Banai et al., 2009). Auditory dysfunction in the cortices or during interhemispheric transfer of information may result in inaccurate frequency and temporal information during the establishment of phonological representations.

The limitations of AP and PWM in individuals with APD may also result in poor comprehension strategies, beginning in the early years. Listening comprehension is an auditory processing task, the product of which is used to access existing phonological and semantic representations. Therefore, the auditory input must be processed efficiently and accurately in order to access the correct corresponding phonological representation and associated semantic representation. The significant correlations between the *SR(C)* and performance on the *CELF-3:LP* for the APD group in both Studies 1 and 2 indicate that PWM plays a vital role in listening comprehension. During the listening comprehension task, we know from SR (C) performance that the APD group had greater difficulty holding the information compared to the NAPD group. It is also known from performance on the PPVT-3 that the APD group had greater difficulty with retrieval of corresponding semantic information, compared to the Average group. The significantly poorer performance on the CELF-3:LP highlights the difficulty that students with APD experience in processing oral language, even in the quiet 1:1 situation.

Speculatively, poor processing of frequency discrimination may have an impact on processing the acoustic contours of words, phrases and sentences with subsequent effects on the prosodic processing for listening comprehension.

During phonetic encoding of sounds, erroneous discriminatory decisions may be made, possibly resulting in inaccurate or unstable phonological representations. Ultimately, the faster a familiar spoken word can be matched and recognized to existing representations the faster it can pass through PWM thus increasing PWM capacity for new information. Weak phonological representations will make the matching process and access to word meanings more difficult. If no match is made, or multiple matches are available, processing will be slowed as a consequence of confusion, or may be impossible. This may explain the correlation between the scores on the *PPS-C(RT)* and scores on the *Sentence Recall* test.

Correlations in previous studies between receptive vocabulary and both listening and reading comprehension have been reinforced in this study. The correlation between the *PPVT-3* and *CELF-3: LP* scores was strong for the APD group, yet non-significant for the NAPD group. Vocabulary scores had a similar range in the APD and NAPD groups, but the standard score range on the *CELF:LP* was much greater for the APD group than the NAPD group. Even when vocabulary was low for participants in the NAPD group, higher scores on the *CELF-3:LP* were achieved. This might suggest that the APD group is more dependent upon vocabulary understanding for oral language comprehension, and perhaps less able to take advantage of prosodic information to assist understanding. For instance, the APD population may be attempting to understand spoken language by focusing on highly imageable key words within the stimulus in order to obtain meaning.

In contrast, the NAPD group possibly has greater capacity available for higher level linguistic and metalinguistic processing during the listening comprehension task. Participants in the NAPD group were perhaps able to get the ‘gist’ or main idea of the overall paragraph from the available linguistic and non-linguistic information. This was supported by this study. Even though there was no significant difference in overall performance on the test of listening comprehension, the APD group performed more poorly on the Main Idea and Inference comprehension question types than the NAPD group, supporting the findings of Cain, Oakhill and Lemmon (2004).

This study has not evaluated all the contributing aspects of listening comprehension. Nevertheless, it is clear from the findings that many individuals with APD need assistance in both educational and everyday situations where listening comprehension is required.

7.5 Reading

This study explored the relationship between receptive language and (word and text) reading ability. It is known that children with language impairments, including those with poor vocabulary and poor listening comprehension typically expereince difficulty learning to read (Gathercole, 1995). Auditory processing deficits are only one possible cause of these linguistic deficits. It was found that AP deficits, particularly PWM deficits, were associated with vocabulary, listening comprehension and reading comprehension performance. Importantly, significant correlations were found between both of the receptive language tests, the *PPVT-3* and *CELF-3:LP*, and performance on the *NARA:RC* in the APD group. A similar relationship was not found in the NAPD group nor the Average group.

A non-significant difference between the reading performance of the APD and NAPD groups is not surprising given that perceived academic underachievement was a major reason for referral to the audiology clinic for AP assessment. The correlations mentioned above, between receptive language and reading comprehension found in the APD group cannot be applied to the lowered reading comprehension scores of the NAPD group, suggesting that reading performance in the NAPD may have been lowered due to a different set of factors such as attention and/or visual processing. Visual processing was not explored in this study. In relation to attention, 14 participants in total had been diagnosed with ADHD; 5 participants in the APD group and 9 participants in the NAPD group. Two of the APD participants and five of the NAPD participants diagnosed with ADHD were taking prescribed stimulant medication. Given these low numbers, it is not possible to draw any conclusions about attentional abilities.

The lack of correlation between listening comprehension and reading comprehension in either the NAPD or Average reader group was unexpected. The NAPD group achieved a higher mean standard score on the listening comprehension task than on either the receptive vocabulary or reading comprehension tasks. This is an interesting finding that warrants further investigation as to whether non-linguistic factors such as the suprasegmentals of spoken expression (processing of frequency, rhythm and stress) or other comprehension strategies assisted listening comprehension in the NAPD or Average reader groups. Overall though, it is possible to conclude that listening comprehension cannot reliably predict reading comprehension performance.

7.5.1 Letter-sound Correspondence

There was no significant difference in the letter naming ability (e.g. ‘b’ = ‘bee’) or letter-sound correspondence (e.g. ‘b’ = ‘b’ as in first sound of ‘boy’) between the APD and NAPD groups on the *WRMT: Supplementary Letter Checklist.* This is a skill usually established in early schooling and therefore differences may have existed at an earlier stage of development. However, the correlation between letter naming ability and letter-sound correspondence was poorer in the APD group than either the NAPD group or Average group. Therefore, participants in the APD group knew the ‘same’ number of letter-sound correspondences as the NAPD or Average groups, but the knowledge of one aspect did not predict knowledge of the other aspect. In the Average group the correlation of 0.99 was near perfect for knowledge of both aspects, compared to the correlation of 0.43 for the APD group in Study One and 0.33 in Study Two. It has been suggested that both PWM and phonological awareness are required for efficient acquisition of sound-letter correspondence in early schooling (Bishop, 2002). The findings suggest the weakness lies in the pairing and/or association of letter names to letter-sound correspondences. Therefore, it would seem that the APD group have a poorer semantic representation of letters, shown by reduced associations of name knowledge with letter-sound knowledge. The greater the accuracy and reliability of the phonological representation of a sound, the more readily the association can be made when introduced to a letter-sound pairing during early reading instruction. If, however, presentation of a letter-sound pair cannot be associated with an existing ‘sound’ representation, it will need to be acquired as novel information. Storage of new information is of course, much more taxing when it cannot be linked with existing associations. Herein lies the importance, during teaching, of associating new letter-sound correspondences to existing information for the learner e.g. the letter ‘m (em)’ makes a ‘mmm’ sound like at the start of ‘mum’ or ‘mint’. By making the association explicit, both storage and retrieval processes will be assisted.

7.5.2 Phonological Mediation

There are two pathways for accessing lexical-semantic representations: via the *phonological input lexicon* or via the *orthographic input lexicon,* as shown on the PALPA model (Figure 1). During normal reading, the *phonological input lexicon* is triggered by either sounding the word (decoding) prior to recognition or via phonological mediation after recognition.

One way to understand phonological mediation is to consider the reading process in the hearing impaired population. A hearing impaired person who utilizes signing for communication, will also sign while reading i.e. orthographic to signing conversion. Comprehension is impaired in this population if signing is inhibited during the reading task (Perfetti & Sandak, 2000). Phonological mediation is the correlate for signing in the hearing population and this study has shown that the less-skilled readers with APD are not competent decoders, as demonstrated by significantly poorer word attack abilities compared to the Average group.

7.5.3 Reading Accuracy

Reading performance was not significantly different between the APD and NAPD groups. However, the mean standard score for both the APD and NAPD groups was below the chronological age mean for reading accuracy. In both groups, performance on the word reading tests was strongly correlated with text reading accuracy, with word identification explaining the greatest percentage of the variance on multiple regression analysis. In the APD group, both vocabulary performance and performance on the *PPS-C(LT)* explained the greatest percentage of variance in word identification. Interestingly the scores for the *PPS-C(L)* and *PPS-C(LT)* also correlated strongly with standard scores on both word reading tests in the APD group. If the establishment of phonological representations relies upon the frequency and temporal information received then it can be speculated that efficient acquisition of letter-sound correspondences may be influenced by the quality of those phonological representations. In turn, word attack and word identification skills are underpinned by stable letter-sound correspondences. A low correlation between letter naming and letter-sound correspondence in the APD group compared to a high correlation for the Average group indicates that the associations between letters, letter names and letter-sound correspondences are not being effectively acquired.

In the APD, NAPD and Average groups, Word Attack and Word Identification scores on the *WRMT* correlated strongly with *NARA: RA* ability (ranging from *rho* = 0.61 to 0.84). The findings of this study showed that word attack and word identification were highly correlated with reading accuracy in the

APD group at *rho* = 0.62 and *rho* = 0.72 in Study One and *rho* = 0.63 and *rho* = 0.84 in Study Two respectively. Slightly lower correlations were found in the Average group of *rho* = 0.61 and *rho* = 0.66 respectively. In the NAPD group the correlations were higher at *rho* = 0.83 and *rho* = 0.82 respectively. Multiple regression also showed that word identification explained 54.1% of the variance of reading accuracy, but at 54.1% word identification alone cannot predict reading accuracy. The model of best fit for reading accuracy included reading comprehension, vocabulary, word identification and the *PPS-C (RT)*, accounting for 88.8% of the variance.

In summary, frequency discrimination, vocabulary and word attack (letter-sound correspondence) accounted for the greater proportion of variance of reading accuracy scores, but there was little evidence of any relationship with dichotic listening or interhemispheric transfer of information. So it would seem that it may be that actual pitch processing, language skills and phonological awareness are more relevant for reading accuracy performance than AP skills.

The findings support the contribution of reading comprehension to reading accuracy, with 75% of the variance of reading accuracy predicted by reading comprehension alone. It would seem therefore that text reading accuracy is a mutually dependent blend of rapid word identification and contextual understanding. This is in accordance with Nation and Snowling (1998b) who found that reading accuracy was poorer than predicted from word identification when reading comprehension was also poor and reading accuracy was better than predicted from word identification when reading comprehension was good. When reading comprehension was poor, the readers were less sensitive to contextual linguistic cues that may have assisted the accuracy of low frequency words, less imageable words and complex irregular words in particular. Accurate text reading is more than the identification of a series of words. The factors which affect reading comprehension, namely phonological working memory and language also impact on text reading accuracy. Clinically, this is a valuable insight, whenever reading accuracy does not appear to reflect word identification abilities.

7.5.4 Reading Comprehension

Reading comprehension ability was significantly poorer in the APD group compared to the reading-age matched Average reader group. This study has found significant correlations between PWM and reading comprehension in the APD group, supporting the findings of previous researchers (Mann et al., 1984; Shankweiler, 1989; Swanson & O'Connor, 2009). Receptive vocabulary and reading comprehension abilities were significantly poorer in the APD group compared to the Average group and phonological working memory ability was significantly correlated to both receptive vocabulary and reading comprehension. However, this study cannot definitively answer whether PWM ability contributes individually to: i. the establishment of weak semantic information in LTM; ii. reduced access to accurate semantic information; iii. weak memory for what has just been read or all of the above. The phonological loop within PWM is considered a vital component of vocabulary acquisition, allowing associations with meaning to occur prior to storage in LTM (Gathercole & Baddeley, 1993). It would seem logical that the phonological loop would also assist the associations between information separated by distance within the text as well as associations to existing information in LTM. According to the PALPA model, the semantic representation can be accessed via direct visual identification or via phonological mediation of the visual input. In this study the participants were reading aloud and therefore the input was phonologically mediated, via the *phonological input buffer* and *phonological input lexicon*. Consequently, there would be PWM involvement in processing the print input.

This study found that the correlation of receptive language with reading comprehension was greater than the correlation to single word reading, a task where semantic activation is optional. The *PPVT-3* and *CELF:LP* standard scores were not significantly correlated with Word Attack or Word Identification scores, but were significantly correlated with reading comprehension. When all the AP tests and language tests were included in the forward regression, the *PPVT-3* scores were included in the model of best fit for Word Identification, indicating that vocabulary does indeed make a contribution to word reading. This is in agreement with previous research (Nation & Snowling, 1998b; Gallagher et al., 2000; Share & Leikin, 2004). It is noteworthy that ten of the twenty-eight APD participants in Study One presented with vocabulary performance at or above the mean. Of those ten participants, six also scored at or above the mean on reading comprehension performance, out of a total of seven participants who scored in this range. The pattern was repeated with the subgroup of APD participants in Study Two. Of the eight APD participants who scored at or above the mean on vocabulary performance, five also scored at or above the mean on reading comprehension performance which was the total number of participants who did score at or above the mean for reading comprehension in Study Two. Therefore, it would seem that firstly, not all APD participants were presenting with weak vocabulary and secondly, that reading comprehension ability closely reflected average or above average vocabulary performance. Either a strong vocabulary assists reading comprehension performance, or reading success has enabled average vocabulary acquisition to occur.

When phonological representations of words are weaker, the listening task and semantic activation may be more difficult, but all words have been spoken and are available to the listener. Possibly words of lower frequency, with high neighbourhood density to other known words, longer words and less distinct words (e.g. spoken quietly, quickly or at the same time as noise) will be lost. The listener with APD may attempt to hone in on high information carrying words to assist understanding. During the reading task, low frequency words and longer words may be difficult to recognise and/or decode but so will irregularly spelt words. The consequence is that irregularly spelt key information-carrying words may not be accessed. In both listening comprehension tasks and reading comprehension tasks information is missing, but the pieces of information will be different. It is the combination of weak semantics, poorer decoding and poorer PWM that culminates in poorer reading comprehension. The strain on the system is likely to result in the development of different coping strategies for comprehension. One reader may adopt a summarising strategy, another reader may adopt a strategy based on relevancy while others may adopt inefficient strategies based on processing only the earliest received information (primacy effect) or most recent information (recency effect) i.e. capacity constrained comprehension (Just & Carpenter, 1992).

The results showed that the APD group achieved a lower score on verb knowledge than the NAPD group. Receptive knowledge of verbs was significantly correlated with sentence recall and reading comprehension in the combined APD+NAPD group. As discussed previously, verbs are more abstract and less imageable than nouns or descriptors. Therefore it would seem logical that when the conceptualisation of a lexical item is not readily imageable, then visualisation is unable to compensate for weak phonological memory and representations and acquisition of that item may be affected.

Listening comprehension and reading comprehension performance were significantly correlated in the APD group. However, the assessment of listening comprehension ability as a predictor of reading comprehension performance is potentially erroneous for the APD population, which has poor listening as a core deficit. Gough and Tunmer's (1986) simple view of reading which states the equation that (R)eading = (C)omprehension x (D)ecoding is problematic if one expects listening comprehension performance to be a predictor of reading comprehension performance. Gough and Tunmer (1986) doubted the existence of a skilled decoder with adequate reading comprehension but poor listening comprehension. The presence of AP deficits refutes this doubt. Listening comprehension requires interhemispheric transfer of linguistic information while reading comprehension does not (Michael et al., 2001). In time, an individual with APD can feasibly achieve a standard of reading comprehension which may exceed listening comprehension ability. If proficient reading accuracy is achieved then all words in the text become available to the reader, yet in listening situations spoken input may continue to be lost. Given what is understood about the reciprocal benefits of reading for vocabulary acquisition and PWM performance, the increasing ability to read is likely to ultimately have some beneficial effect upon listening comprehension in this population but measures of listening comprehension performance could seriously underestimate predicted reading comprehension ability in the APD population.

Therefore, despite a moderate correlation in the APD group, listening comprehension did not fully account for reading comprehension performance. This study also found strong correlations between word identification and reading comprehension in the regression analysis, where word identification was the single strongest variable contributing to reading comprehension.

7.5.5 Reading Rate

There was no significant difference between the standard scores for reading rate on the *NARA-3* achieved by the APD group, the NAPD group or the Average group. However, the result approached significance in Study Two, with the APD group showing poorer performance than the Average group. Consequently, it *cannot* be said that the two groups read at the same rate. Rather, reading rate was perhaps slightly better than expected in the APD group given their significantly poorer reading accuracy, as discussed in 7.5.3. The practical importance of this finding is that reading rate may be a poor indicator of reading ability.

In both studies the measure of non-verbal intellectual ability, the *RCPM*, correlated significantly with reading rate in both the APD group and Average group, but no other reading measure. Intellectual abilities were not a major contributing factor to the skills associated with word reading, reading accuracy or reading comprehension but made a contribution to reading rate. Perhaps intellectual ability is an important top-down factor aiding the efficient integration of all the reading subskills, acting to speed up the reading process. The combined implication of the above is that perhaps the average intellectual abilities of the

APD group enabled participants to read at a better rate than might be expected for their word reading, reading accuracy and reading comprehension scores. As described in the literature review, consensus regarding the relationship between intellectual functioning and reading development has not been reached and requires further investigation.

7.6 Reading Errors

In Study One, the total number of errors made by the APD and NAPD groups was not substantially different, with 491 errors made by 28 APD participants (mean = 17.5 errors) and 372 errors made by 20 NAPD participants (mean = 19.2 errors). Yet interestingly, 5% more errors lost the intended meaning of the text in the APD group. The APD group also made fewer visual errors, recasts and decoding errors compared to the NAPD group. In Study Two, again the total number of errors for the APD group and the Average group was similar and there was no substantial difference in the number of errors that lost the meaning of the text. However, it must be recalled that the Average group were matched for reading-age and were in fact, significantly younger than the APD group. Therefore, the APD group was making a similar number of errors and losing meaning at a similar rate as the younger readers in the Average group. However, the pattern of reading errors was considerably different. The APD readers made a greater number of whole word substitution errors (based on word shape or meaning) and fewer recasting or decoding errors.

As outlined in the literature review, three stages of reading development were described by Frith (1986). Initially high frequency whole words are recognised by sight in the logographic stage, then gradually letter-sound correspondences are acquired in the alphabetic stage. In the final orthographic stage, an increasing bank of written words is effortlessly recognised. Typical competent readers will continue to use strategies from all three stages in concert throughout their lifetimes, depending on the demands of the reading task.

During the logographic stage, frequently encountered words are rapidly recognized, usually including the child's own name. This is considered to be analogous to picture recognition processes, as per the PALPA model in Figure 1. However, as the variety of written words expands more errors will occur on presentation of visually similar words e.g. 'yellow' and 'pillow'. For the developing reader, sublexical processes become necessary in order to resolve this confusion. Mastery of the second alphabetic stage is crucial for decoding unfamiliar words.

This study showed significant correlations between frequency discrimination and word reading, as shown in Table 20 in section 5.6 (see also 5.8). Weak frequency discrimination could have an impact on the quality of phonological representations *available* for matching to orthographic representations i.e. single letters, letter chunks and whole words. In the emergent theory of phonemic awareness development, awareness of individual phonemes is raised by the ability to distinguish between phonologically similar words (Metsala, 1999), as explained in the literature review under section 2.5.2. Poor quality phonological representations may impede the discrimination of phonologically similar words and also hinder letter-sound correspondence learning, necessary for success within the alphabetic stage. In turn, poor phonological learning would have an impact on both word attack and word identification abilities and these skills were strongly correlated with text reading accuracy in this study. Correlations and multiple regression analysis in the present study confirmed that word attack and word identification skills account for text reading accuracy.

If decoding is poor in the LSR within the APD group, then it is worth asking whether PWM abilities may be related to the phonological awareness skills necessary for sound-letter correspondence learning. This has been investigated in previous research. Gathercole and Baddeley (1993) explored the relationship between phonological awareness and PWM and concluded that these two variables are dissociated, yet coincide in early schooling to establish early 1:1 letter-sound correspondences. This means that significant correlations between PWM ability and phonological awareness skills have not been found consistently (Bradley & Bryant, 1983; Hull, 1999) yet both abilities have been significantly correlated with reading outcomes. Gathercole and Baddeley concluded that phonological awareness is critical for understanding the segmented nature of words into individual sounds, but efficient PWM is necessary in order to learn the associations between letters/letter chunks and sounds i.e. phonological learning.

Weak PWM has an impact on phonological learning and decoding ability; the product of each letter-to-sound conversion is held within the phonological loop in PWM, after phonological mediation of the letter has been accessed from within long-term semantic memory. At present, it is not clear whether letter-to-sound conversion accesses a) existing phonological representations, used for listening comprehension or b) learned letter-sound associations. Phonological representations are understood to be stored in the middle and superior temporal region while letter-sound associations are possible stored in the left occipito-temporal sulcus, an area known to be activated during word recognition tasks. It is thought that the phonological store may also provide some additional short-term memory space while working memory acts to decode the word (Jones et al., 2004). The activated phonological items must be assembled, held and blended in sequence within PWM. Slow reading increases the real time duration of information within PWM thus acting in a similar way to the word length effect, allowing less information overall to be processed by a system designed to take in input at speaking rate. If the phonological representations are poor or the ability to hold and blend the representations (in sequence) is weak, decoding will be impaired. The significant correlations found between frequency discrimination and word reading in this study perhaps shed some light on one possible underlying cause of poor decoding. Poor frequency discrimination may contribute to the establishment of poor phonological representations that hinder phonological learning and therefore, decoding ability.

Once 1:1 sound-letter correspondences are acquired, phonological awareness and PWM continue to act upon the acquisition of more advanced recoding of letters, now incorporated into chunks (e.g. ‘ph’, ‘ough’, ‘ight’ etc.) as well as orthographic rules such as the ‘c’ being pronounced as the soft ‘s’ prior to ‘e’, ‘i’ or ‘y’ as in ‘city’. Of course, reading experience also helps to reinforce the newly acquired orthographic-phonologic correspondences. Immature 1:1 letter-sound decoding greatly reduces the likelihood of accurate word indentification of an unfamiliar word, especially as text becomes more advanced, containing more digraphs and irregular spellings. For instance, 1:1 decoding of words such as ‘imagine’ or ‘system’ cannot be blended to form the target. Often good readers will accurately guess a word when they achieve a blended form that is close to the target, but the blended forms for the APD population are less likely to aproximate the target if they are blended in a 1:1 manner. The blended attempt that bears no resemblance to the target is the reason that the child appears to sound the word correctly yet not glean any meaning from their efforts. Blending is problematic in the presence of PWM deficits: blending errors occur that may include sound deletions, sound additions, sequencing errors or sound substitutions e.g. ‘grayfish’ for ‘crayfish’. Compounded by loss of meaning for the text, the LSR with APD has a poor chance of correctly decoding the target word.

Analysis of error types for the APD group showed a greater number of substitutions of meaning and word shape and fewer recasting and decoding errors compared to the Average group. Both recasting and decoding errors require auditory retrieval and processing of speech input when performed aloud, creating a load on PWM via the *phonological input buffer* and *phonological input lexicon,* known to be weak for the APD population. Lack of success with decoding may also contribute to the observed preference for whole word substitution as a reading strategy for an individual with APD, holding the reader in the earlier logographic stage of reading development. This study showed that the APD group and Average reader group can be distinguished by their respective error profiles on the *RAP* anlysis.

The APD group was also less successful at self-correcting decoding errors than the Average group. The low success with self-correction of decoding errors may indicate that the decoding product did not result in phonological output that was sufficiently close to its phonological target to trigger the existing phonological representation. This would happen frequently when a reader remains reliant on immature 1:1 decoding strategies. For instance, if the word ‘weight’ is decoded using 1:1 decoding the individual sounds will not blend to conform with the accepted pronunciation of the word. Even a partial decoding attempt of ‘festival’ such as ‘festi-’ may not trigger an existing phonological representation if that representation is poorly specified. Of course, when the phonological representation is not activated, the associated semantic representation is unlikely to be triggered either and the potential for effective top-down processing is restricted.

It is important to point out that many of the ‘errors’ coded in this study could equally be called ‘strategies’. For the sake of disambiguity, it was decided that an error had occurred if the upcoming target word was not read accurately. However, it is certainly acknowledged that when the upcoming word is unfamiliar to the reader, there are some strategies that are more helpful than others to achieve accuracy. In particular, this study has highlighted that recasting the preceding phrase is highly successful for the Average reader and age-appropriate decoding is more successfully self-corrected by the Average reader than the LSR with APD. In contrast, the APD group was more successful at self-correcting substitution errors.

Reduced application of recasting to assist accuracy may be an important factor in LSR. The typical approach to an unfamiliar word by participants in the Average group was to pause then either decode or recast the preceding phrase. Interestingly, it was observed that recasting generally occurred even when no error had been spoken aloud. In contrast, even though recasting was 92% successful for the APD readers it was rarely used. The few instances of recasting that occurred in the APD group did so *after* an error had been made, suggesting a reluctance to apply this strategy. This reluctance could be attributed to either weak language abilities, weak PWM or both. In addition, weak PWM has established an impoverished semantic underpinning for the reading task. Recasting makes demands on the semantic system and PWM as the phrase or sentence is re-read; decoding makes demands on letter-sound correspondences and phonological representations of lexical items as well as PWM. In comparison, whole word substitution places little *extra* demand on PWM beyond the demands that already exist for processing the meaning of the text.

Errors classified in the ‘Visual’ category, such as reversals, deletions, additions or losing the place on the line or within the paragraph do not assist reading accuracy unlike the strategies mentioned above. Both the APD group and the Average group made fewer visual errors (losing the place in text, letter reversals, word reversals) and deletion errors than the NAPD group. This suggests that other factors may be affecting reading performance in the NAPD group.

The APD group had significantly poorer receptive vocabulary knowledge than the Average group. In the period while decoding skills are developing, blending individual sounds together is unlikely to result in the target word, unless that vocabulary item exists in the phonological input lexicon (Nation & Cocksey, 2009). Further, Nation and Cocksey (2009) found that phonological representations were more important than semantic representations for reading at the word level. They also found that the existence of a phonological representation was even more important for reading irregular words than regular words. Unfamiliar regular words can be successfully decoded by sublexical processing and are therefore less reliant on existing vocabulary. Even if a regular word is correctly decoded, there will be no semantic representation to be accessed if the word is not in the lexicon. In the early stages of decoding, there is a greater reliance on context. When vocabulary knowledge is low LSR will experience a processing overload that is not relieved by contextual assistance (Nation & Snowling, 1998b). Impoverished vocabulary knowledge, as shown by the APD group in Study Two, will therefore cause a drag on word identification from the outset of reading instruction.

Plaut et al. (1996) hypothesized that reading is actually a 'division of labour' between firstly, mapping phonological information onto orthography and secondly, a semantic process of mapping meaning to both the orthographic and phonological representations. They found that phonological processes continue to be used for reading regular words, but that with input from semantics, phonological processes were less important for reading irregular words. Put simply, the connectionist model represents reading as a process drawing upon orthographic, phonological and semantic information with constantly shifting weight between the three inputs. It is important at this juncture to consider the effects of weakness in any one of these areas, the consequence of which may add disproportionate weight to other areas.

As the comprehension demands of reading increase, the need for rapid word recognition becomes greater, allowing maximum capacity for higher level linguistic processing and comprehension (Oakhill et al., 2003; Catts et al., 2005). When PWM is poor there will be less capacity available for the construction of meaning, especially if language skills are also poor. This finding emphasizes the ongoing importance of language abilities for reading comprehension. If an individual with APD is not getting linguistic input from reading, their language skills may continue to hamper reading progress. In contrast, if the individual with

APD is assisted to become a good reader, the reciprocal benefits to language development may help to gradually compensate for linguistic deficiencies.

The decoding effort for the LSR with APD reduces the capacity available for higher level linguistic and metacognitive strategies to act on interpretation of the text. As outlined in the literature review, Coltheart et al. (1994) proposed that during reading, orthographic input activates phonology in a cascading fashion with progressively greater segments of the word phonologically converted until an acceptable semantic ‘fit’ is achieved. Therefore, the sooner that whole word identification is achieved, the more fluent the reader becomes.

The APD group had significantly poorer PWM, poorer receptive vocabulary (and therefore a weaker *semantic system)*, poorer phonological decoding ability and poorer word identification than the Average reader group. The consequence with regard to capacity theory and division of labour is that the capacity remaining for linguistic and cognitive processing would be reduced in these less-skilled readers.

While the evidence for auditory processing deficits in the dyslexic population is mounting, the reading pattern of the majority of students diagnosed with auditory processing disorder in this study was not consistent with dyslexia. For instance, participants in the APD group did not evidence notable letter or word naming difficulty, letter confusions or marked difficulty with the reading of nonwords greater than real words. Errors in word identification tasks have shown that readers with dyslexia have difficulty retrieving the phonological code for words contained in the lexicon whereas LSR have a reduced lexicon (Swan & Goswami, 1997b), consistent with the findings of this study. For instance, under-activation of the left inferior frontal gyrus (Broca’s area) in dyslexics during phonological tasks is suggestive of reduced *access* to the phonological representation (Goswami, 2000). Swan and Goswami (1997a) found that errors made by dyslexic readers generally retained the same initial letter/sound and same syllable length as the target compared to the errors made by LSR. It is possible that the *RAP* analysis may be able to differentiate less-skilled readers from dyslexic readers as well as average readers.

7.6.1 Summary of Reading Errors

Previous research has suggested that readers with phonological deficits will not use phonology if it is not required by the task (McNeil & Johnston, 2004). The error pattern displayed by the APD group suggests reluctance to decode in this group, possibly due to an accumulated experience of failure. Decoding errors were self-corrected with 9% success in the APD group compared to a 16% success rate in the Average group. Instead the APD group tended to substitute the whole word with a word of similar shape or another word that makes sense in the sentence. Whole word errors rather than part word errors reflect an earlier developmental pattern (McGuiness, 1997). Substitution of a visually similar word was self-corrected with 18% success and a substitution based on meaning was self-corrected with 24% success in the APD group, compared to 8% and 0% respectively in the Average group. Therefore, it would seem that the lexical strategies used in the APD group were less successful for the Average group. In contrast, recasting errors were 100% successful for the Average group compared to a 92% success rate for the APD group. This study would seem to corroborate the finding by McGuiness (1997) that whole word errors negatively correlated with reading ability.

The less-skilled reader with APD does not seem to be an effective decoder: decoding is effortful and only 9% of decoding attempts led to correct pronounciation of the target word, compared to 16% for the significantly younger Average reader. As outlined in the literature review, phonological awareness and PWM combine to develop sound-letter correspondences during early reading instruction. Deficits in either area hinder the progress of this vital acquisition process.

The APD group made fewer recasting and decoding errors on average than the NAPD group in Study One, and this was more pronounced in Study Two. Both recasting and decoding rely on PWM, and so it seems likely that LSR with APD avoid these strategies as they are generally less successful for them. Instead they maintain the less developmentally mature strategies of substitution. Word attack skills were significantly poorer in the APD group compared to the Average group indicating significantly poorer decoding ability. It would seem therefore that weak PWM ability hinders successful sound blending and renders recasting the sentence impracticable.

7.7 The Directional Flow of Information Processing

Every time the listener experiences an *auditory perceptual event*, processing of the auditory stimulus interacts with higher level auditory and linguistic processing, attention, memory and cognition (Tyler, 1992). Even though it is now widely accepted that these top-down and bottom-up processes occur interactively and simultaneously, investigation of the contribution of each element in the information processing model remains a worthy pursuit.

This study confirmed that the APD group has significantly poorer receptive language and reading ability compared to the Average group. The study has attempted to investigate the contribution of auditory processing to receptive language and reading performance. The linguistically loaded *SR* test of PWM was moderately-to-strongly correlated with vocabulary, listening comprehension and reading comprehension in the APD group. The overall severity of AP deficits also correlated moderately-to-strongly with both vocabulary and listening comprehension. Clearly, these tests do not eliminate linguistic difficulty as a common denominator. However, the use of non-speech tests in this study greatly reduces the linguistic load within the AP task. With the temporal order component of the *PPS-C* score having been removed, the non-speech tests yielded correlations between frequency discrimination ability and PWM. Moderate to strong correlations were also found between frequency discrimination and word reading.

The PWM ability of the APD group was significantly poorer than the NAPD group and given average sentence recall in the Average group it can be assumed that PWM was also poorer than in the Average group. However, PWM ability is also known to be poor in individuals with language impairment, presumably due to the interference of inefficient phonological and/or linguistic processing. There have been at least three overlapping proposals from a developmental perspective that are relevant to this investigation and these are:

1. That combined PWM and AP deficits are a risk factor for language difficulty (Bishop, 2002; Dawes & Bishop, 2009);
2. That combined PWM and linguistic deficits are a risk factor for literacy difficulty, especially reading comprehension (Bishop, 2001);
3. That combined PWM and phonological deficits are a risk factor for literacy difficulty, especially reading accuracy (Gathercole & Baddeley, 1993).

The effect of PWM limitations upon language and literacy development is fast becoming a major tenet of reading research. This current study perhaps strengthens and extends the above proposals, by proposing that combined AP and linguistic deficits are a risk factor for PWM difficulty. Consider that prior to 5 years of age, nonword repetition ability (PWM) predicts vocabulary performance, but after 5 years of age vocabulary performance predicts later nonword repetition ability more strongly than the reverse (Gathercole, Pickering, Ambridge et al., 2004). The flow of causation, at least after 5 years of age, would be AP deficits + linguistic deficits → PWM deficits → reading deficits rather than AP deficits → PWM deficits → linguistic deficits → reading deficits. Referring back to the PALPA model, the proposition is that inefficient *auditory phonological analysis* plus inefficient retrieval of information from the *semantic system* combine to undermine the matching processes within the *phonological input lexicon* that are necessary for rapid recognition. Without activation of the accurate phonological representation in the *phonological input lexicon*, neither semantic activation into

PWM for comprehension nor storage of new information into LTM can take place.

There is evidence to support the above proposition. In the present study, both dichotic listening ability and performance on the *PPS-C* correlated significantly with PWM performance, but not to receptive language or reading comprehension abilities. However, PWM performance correlated moderately-strongly with receptive language and reading comprehension. This would appear to indicate that both AP deficits and linguistic deficits undermine PWM. If AP deficits (or severity thereof) have an impact on language acquisition via PWM, one might expect some consistent significant correlations between AP performance and the linguistic tasks. Apart from a negative correlation of *CS* (*Weak Ear*), only the *SSW non*-competing condition scores and *SR(C)* scores correlated with language skills. The consequence of the current proposition is that it would be more expedient to develop AP skills and language skills to improve PWM than to attempt PWM development in isolation.

The research group Hornickel, Skoe, Nicol, Zecker and Kraus (2009) have amassed evidence over a number of studies, providing neurophysiological evidence of abnormal phonological perception in the presence of working memory deficits. It might be argued that the co-morbidity of abnormal neurophysiological responses to speech and the presence of PWM deficits is coincidental. However, as AP skills improve so does PWM ability. In a longitudinal study of children diagnosed with APD, tested at 7 to 8 years of age and again at 8 to 12 years of age (Stanley, 1999), all AP skills tested had improved, but performance on the *Sentence Recall* test showed the greatest improvement. When AP skills were poor, so too was performance on *Sentence*

Recall, but when AP skills improved, *Sentence Recall* performance greatly improved. Further, it has been shown that as language skills improve so does PWM ability. Montgomery (2003) found that language impaired children had comparable PWM to younger language-age matched children, but poorer PWM compared to their age-matched peers with normal language abilities. The findings from both studies could be interpreted as evidence that AP skills and language skills determine PWM functioning and not the other way around.

The listener applies certain expectations or hypotheses to the input in a top-down approach, but constantly cross-checks with the bottom-up signal to substantiate the hypotheses being dynamically constructed. There is a constant oscillation between processing of the signal and higher order processing. The major factors that determine whether lower order or higher order processing must be employed is the quality of the signal and the predictability of the input (Duchan & Katz, 1983). Embedded in linguistic knowledge are expected communication rituals such as greetings and conversational conventions. For instance, if one person asks “How are you?”, the expected response may be ‘good’ or ‘fine’. When the response is instead “I’m feeling terrible today” the expectation has not been met. It is arguable whether the input is processed via analysis of the actual acoustic features of the signal or a ‘perceptual match’ between the input and the expected representation (Kent, 1997). The former view proposes that a person has generated an expectation hypothesis and is expending cognitive energy testing that hypothesis. The latter view proposes that the person is expending less cognitive energy, and is relying upon thresholds of perceived acceptability of the expected input. Either way, auditory, linguistic and cognitive processes are acting simultaneously.

People experiencing symptoms of APD will often report that they are assisted by repetition of the linguistic input, a slower rate of delivery or simplification of the input. The individual preferences here may reflect speed of processing, figure-ground and/or linguistic deficits. It is likely that the process varies depending upon the individual, the circumstances (e.g. foreign speakers, complexity of message) and the acoustic environment. The degree to which an individual copes with any auditory processing deficits may be related to the individual's style of processing information via the data-driven or concept-driven approach. It may also explain why clear correlations between auditory deficits and higher order language and literacy skills have been elusive.

7.8 Limitations of the Present Study

Given this study was a cross-sectional comparison study, it was not possible to draw developmental conclusions about semantic and phonological acquisition. For instance, it is impossible to say to what extent the extraction of meaning can be attributed to the status of the acquired semantic representation and to what extent it can be attributed to access to the existing representation. While this study is able to report poorer AP, receptive language and reading performance in the APD group it is not possible to draw conclusions on whether AP abilities affect semantic and phonological representations, retrieval processes and/or PWM for semantic and phonological information. Nor is it possible to be certain about the directional relationships between auditory processing, phonological working memory, receptive language and reading. This would be a valuable pursuit following from this research.

Performance in the left and right competing condition on the *SSW* test and ear performance on the *CS* test was analysed in this study, but not the degree of right ear advantage i.e. the discrepancy *between* right and left ear performance. A closer analysis, taking this aspect into account may yield further insight into the nature of AP performance and the effect on language and literacy performance. Additionally, other patterns of performance e.g. recency and primacy effects on all the tests in the FUSAPB could be analysed to investigate the effects of fade compared to speed of processing.

While the results indicated that interhemispheric transfer of auditory information was implicated in PWM performance, it was not possible to determine whether this finding might represent an integration disorder. This would require confirmation that prosodic processing such as frequency information was not being simultaneously integrated with linguistic processing, with consequent effects on oral comprehension.

The APD group showed poorer decoding ability in both word reading and text reading tasks, but it was difficult to determine the extent of the poorly developed decoding abilities in greater detail. Participants in the APD group did have difficulty decoding the items containing vowel digraphs (e.g. ‘ir’ in ‘zirdn’t’, ‘ou’ in ‘gnouthe’, ‘au’ in ‘vauge’) in the word attack subtest. While this suggests immature decoding abilities, it would be valuable to test the vowel digraphs isolated from the word context as a purer test of letter digraph-sound correspondence. Phonological awareness performance it not known in this study, but is known to be a relevant factor in letter-sound acquisition, most likely more evident at an earlier stage of development than the age of the groups under investigation here. Additional time might also have allowed a thorough analysis of the letter combinations contained within each reading error in the text reading, but this is probably not the most efficient procedure to achieve a comprehensive profile of advanced decoding ability. Instead, paragraphs specifically designed to evaluate a range of orthographic contexts may be may be more suited to the purpose.

This design of this study did not extend to investigation of the cause of sub-optimal reading in the NAPD population. Unlike the APD group, *all* participants in the NAPD group performed within or above the average range on the *CELF-3:Listening to Paragraphs* subtest and *WRMT:Word Attack* subtest, suggesting better phonological working memory and phonological (letter-sound correspondence) skills than the APD group, thought the difference was not significant.

It was not practicable to perform the auditory processing battery on the Average group participants. There was no indication of AP difficulty in the Average participants given their average ability on the sentence length, receptive language and reading tests. Therefore, no AP testing was performed for this group. However, data on AP performance would have allowed further comparisons between AP tests and both receptive language and reading performance in this group.

Further aspects of performance that might have added value to the study include tests of attention, visual working memory and language assessments, including syntactical abilities. This study implicates AP skills and PWM performance in literacy outcomes, but cannot rule out the involvement of generalized attention, memory or further linguistic variables not included in this study.

7.9 Further Research

7.9.1 Auditory Processing

Greater consensus on the definition and diagnostic procedure/s for APD is needed in order for APD research to be comparable across studies. Decisions need to be made regarding mandatory tests and whether the assessment protocol must include failure on non-speech tests. Some researchers insist that under present methods of assessment, APD diagnosis should be a collaboration between the audiologist and the speech pathologist to balance the audiological findings against known language abilities (Moore, 2006; Dawes & Bishop, 2009). However, the possibility that formal diagnosis will be made on the basis of neurophysiological evidence is fast becoming a reality. The use of auditory brainstem responses (ABR) and cortical evoked potentials such as those recorded using electroencephalography (EEG), functional Magnetic Resonance Imagery (*f*MRI) and positron emission tomography (PET) in response to speech and non-speech input is undoubtedly going to provide valuable insights for 1) improved APD nosology and 2) language and reading research. These procedures are now available to many audiologists associated with major hospitals and clinics. It is exciting that Johnson et al. (2005) believe that viable techniques of evaluating brainstem responses to speech sound input, such as BioMAP will ultimately become a method of easily detecting biological markers of auditory processing disorders of speech perception, possibly from infancy. Additional use of neurophysiological measures to monitor brain function during a range of both language and literacy tasks will afford further insights into the neural pathways and cortical areas responsible for normal and abnormal information processing. As with any disorder, the aetiology of APD requires ongoing investigation, even if the cause is unlikely to be attributable to a single source.

A gap in the research exists around the size of the unit processed by the auditory system. In particular, the extent to which information from the acoustic signal influences perception is critical to our understanding of language processing and development. It is possible that the efficiency of auditory processing may affect the size of the unit that is comfortably processed as a ‘chunk’. However, determination of whether spoken input is processed at the phonemic, syllabic, lexical, phrase level or higher would lead to greater understanding of the mechanisms within phonological working memory and linguistic development. Further, the *consistency* of the response to input for individuals with APD is worthy of investigation, possibly through comparison of brainstem and cortical responses to repetition of the same input.

A number of studies have found that poor readers have difficulty with rapid processing of the temporal order of two tones of different frequency (Tallal, 1980; Cestnick & Jerger, 2000; Fischer & Hartnegg, 2004; Cohen-Mimran & Sapir, 2007), but replication of these studies has been fraught with conflicting results. There is now mounting evidence that poor readers have difficulty with frequency discrimination (Witton et al., 1998; Talcott et al., 1999; Sharma et al., 2009). The common factor in these studies is that the performance on the task (frequency discrimination and temporal ordering) breaks down at short ISIs. That is, the poor readers have difficulty detecting rapidly presented acoustic changes. The combined evidence now seems to suggest that frequency discrimination and detection of frequency modulation is poor in poor readers, but inefficient processing of frequency is only revealed when challenged by rapid processing tasks. Share et al. (2002) found that children at school entry age who had difficulty on the ART test (used by Tallal) at longer ISIs than those reported by Tallal (1980) were later diagnosed with reading difficulties. These findings suggest that frequency discrimination difficulty may be more readily observable at longer ISIs in younger children.

The processing of frequency discrimination and acoustic contours warrants further investigation due to the significant correlations between the *PPS-C* with both receptive language and reading comprehension performance found in this study. While the findings from this study in this area are preliminary at best, it would appear that right ear processing of frequency was associated with language processing (sentence recall) while left ear processing of frequency was associated with phonological processing (nonword and single word decoding). It would seem logical that PWM ability would be enhanced by efficient integration of language processing in the left hemisphere and the correpsonding acoustic contour processed in the right hemisphere i.e. integration of auditory and linguistic information. If frequency discrimination, sequencing and PWM for acoustic contours are indeed critical for the development of well specified phonological representations and a rich semantic system, then it may be valid to promote remediation programmes that target development of processing frequency information. It would seem that a standardised dichotic pitch processing test would be a valuable inclusion in the AP test battery, because it adds information regarding interhemispheric transfer of non-speech input to the dominant right hemisphere for pitch processing, via the corpus callosum. If frequency discrimination is having a detrimental effect on PWM, PWM functioning is being influenced by a signal integrity effect, whereby the original integrity of the signal is not maintained by the auditory system.

The findings of this study suggest that frequency discrimination and/or temporal ordering (as measured on the *PPS-C* test) plays a more significant role in reading performance than rapid temporal resolution (as measured on the *RGDT*) and this accords with the findings of Sharma et al. (2006; 2009). Reflecting upon previous research which has found participants to have difficulty detecting the order of two tones of different frequency with shorter ISIs (Tallal, 1980; Cestnick & Jerger, 2000; Fischer & Hartnegg, 2004) perhaps an alternative explanation could be that frequency discrimination is poor (and slow) but this is only detected when challenged by short ISIs. The Auditory Repetition Test (ART) used in these previous studies requires auditory discrimination, temporal ordering and rapid perception. The *RGDT* used in this study requires rapid perception of an inter-stimulus interval, without any frequency discrimination or temporal order judgement demands. Given the *PPS-C* scores were correlated with word attack and word identification scores but the *RGDT* scores were not, this indicates that it was the frequency discrimination and/or temporal ordering aspects of auditory processing are related to reading performance. This conclusion is possible even though frequency discrimination and temporal ordering had met criterion on the ART at slower delivery rates. An individual may be having difficulty with a skill, that is not detectable until tested at speed. Clearly this contention that the frequency discrimination aspect rather than the temporal resolution aspect of AP has a more significant impact on word reading requires substantiation from future research.

Finally, the value of primacy and recency effects in short-term memory and PWM tasks warrants further investigation. When information processing is slow, possibly due to poor phonological representations, this may show up as a primacy effect whereby earlier auditory input is recalled in favour of recent input (that is yet to be processed) during PWM tasks (Medwetsky, 2002a). This contrasts with the recency effect that occurs when earlier information is lost, possibly due to a weak phonological loop, and only the most recent information is recalled. Qualitative analysis of responses on the SSW, CS, STM and PWM tasks may shed light on the aetiology of poor performance.

Subtyping of APD, as proposed in the Bellis and Ferre model (Bellis, 2003) may also add value to APD research. At present, however, it is widely agreed that these subtypes presently require validation from large scale studies.

7.9.2 Phonological Working Memory

This study has highlighted the relationship between PWM, receptive language and reading performance. The potential for PWM to become a predictor of language and reading ability could be explored in greater depth. Initially, the development of a range of standardised tests for PWM, including individual sounds, real words and nonwords in isolation, phrases and sentences is needed.

The exact nature of the effect of auditory integration deficits, as well as the impact of the frequency, temporal and intensity domains, upon PWM need to be determined, ideally across developmental stages. One important consideration for the population with APD is that if the concomitant language deficits are the consequence of inefficient PWM, then the language system itself may have the potential for normal levels of functioning and comprehension given the opportunity to experience an alternative mode of input e.g. reading. In this study, language performance was significantly poorer in the APD group compared with the Average group. However, if reading improved to average status, it would be valuable to re-evaluate language skills (via reading comprehension and language expression) to determine whether the language system had also attained normal levels of functioning.

Of the effects known to reduce PWM function, namely word length effect, phonological similarity effect and articulatory suppression effect, only the phonological similarity effect has not been explained. If individuals with APD have poorly specified phonological representations, an enhanced phonological similarity effect would be expected in this population. Although a more pronounced phonological similarity effect has not yet been demonstrated in the APD population, there are methodological reasons why this may have occurred e.g. ceiling effects and further investigation is warranted.

This study has therefore opened up a new line of enquiry: Is PWM a symptom or a cause of phonological and/or linguistic developmental status? For example, consider whether combined AP deficits and PWM deficits contribute to language weaknesses or whether combined AP deficits and language deficits contribute to PWM weaknesses. We know that reading success will lead to improved PWM, but there may also be pre-literacy strategies that will optimize PWM development. For example, perhaps deliberate gradual increases in the length of utterances that children are exposed to in the home environment may assist processing of gradually larger amounts of information. Similarly, utterances containing linked concepts that are separated by increasingly greater distance, may also improve PWM performance. The progress of these systematic strategies could be monitored by a speech pathologist, as part of a language therapy programme, in order to guide the child towards a skill level commensurate with chronological age.

7.9.3 Listening comprehension

A controlled study could include children diagnosed with APD in which firstly, the receptive knowledge of all the information-carrying words embedded within a written text in the study group is ensured. This stage would be followed by an evaluation of the reading errors and strategies used while reading that text. This method would assist in differentially determining the effects of vocabulary upon reading accuracy separate from the effects of reading strategies. In particular, observations of children decoding words that are known to be in their lexicon, allows the researcher to observe why the target is not achieved i.e. what aspect of decoding did not allow the existing phonological representation to be activated? This would further assist in understanding how altering one aspect of associated difficulty may affect overall reading improvement and ultimately assist in prioritizing objectives in the reading remediation programme.

The finding that verb knowledge was correlated with PWM and reading comprehension performance has singled this out as an interesting line of pursuit for research. Again, if further evidence were to confirm that breadth of associated phonological representations and richness of semantic representations for verb knowledge led to marked improvement in listening comprehension performance, this knowledge could be readily applied to home, classroom or clinical intervention for children with APD who show deficits in this area. Also, investigation of why this pattern emerges would lead to a greater understanding of whether children with APD are influenced by the shifting morphology of verbs, the number of verb referents in the sentence and/or the degree of abstractness or imageability in conceptual representation. Of course, investigation of other word classes and words of gradated abstractness would also enhance knowledge of this area.

7.9.4 Phonological Mediation

One major consideration for revision of both the PALPA and DRC models is that research regarding phonological mediation suggests that both the orthographic input lexicon and letter-sound conversion activate the phonological input lexicon which in turn activates the semantic system during reading (Van Orden, 1987; Luo, 1996; Brysbaert, Grondelaers et al., 2000). Current thinking is that phonological activation leads word recognition. Successful phonological activation sets up a feedback mechanism between phonology and orthography in what is now referred to in the literature as ‘fast’ phonology (Rastle, 2007). This has been supported by recent research and consequent reading models such as the bi-modal interactive activation model (Frost & Ziegler, 2007). The major question to be resolved is whether a direct visual-to-semantic processing route exists at all. A modified PALPA model that acknowledges phonological mediation while keeping the visual-to-semantic route open, awaiting further evidence, is provided below in Figure 11. The proposed model for processing auditory and print input (PAPI) is applicable to single word reading, reading aloud, spoken repetition of words and sentences as well as novel formulated utterances. The PAPI model may be useful in future reading research.

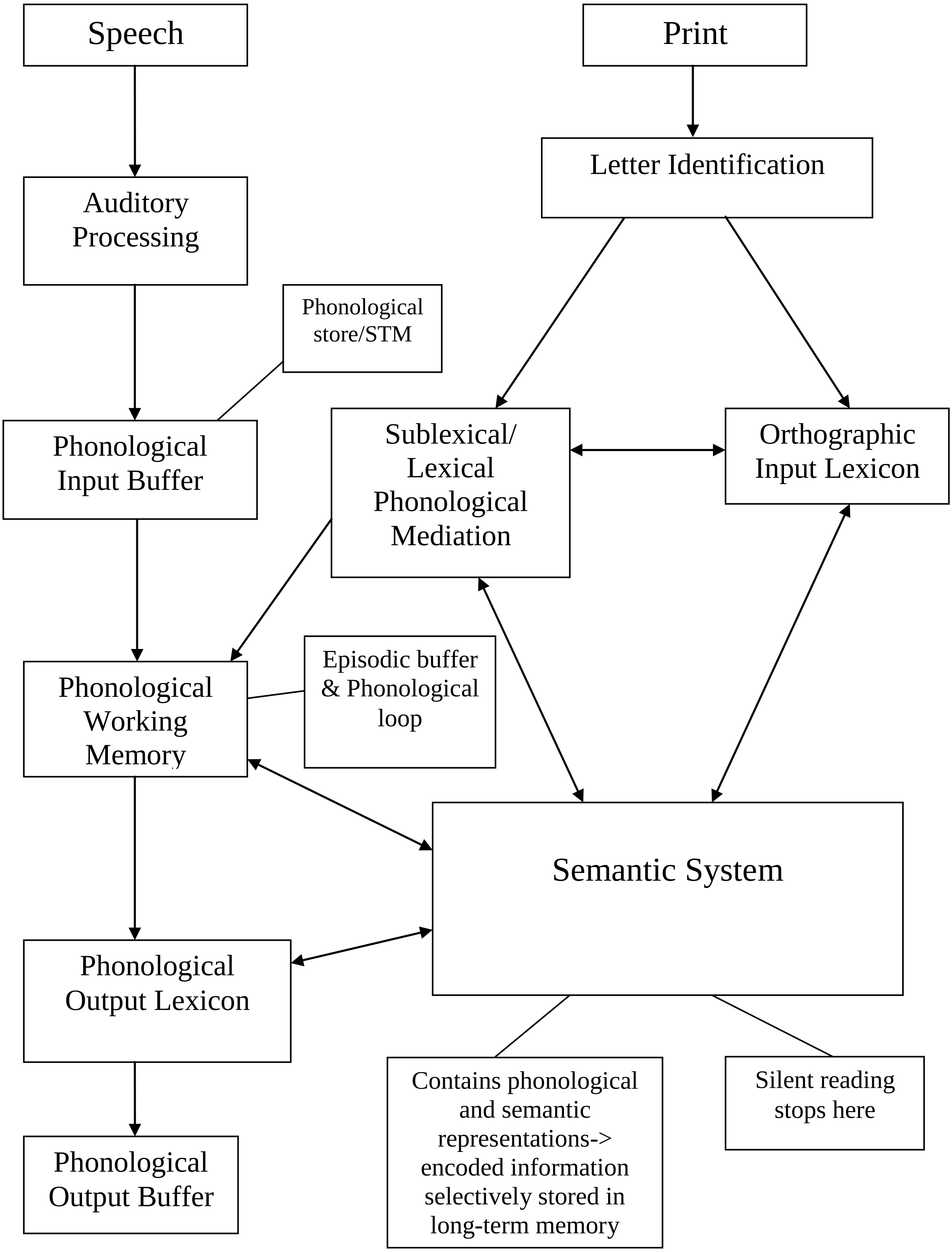


FIGURE 11:
A modifed PALPA model: Processing auditory and print input (PAPI) model.

The PAPI model emphasises the overlay of literacy onto the existing phonological and linguistic system for speech. One very important aspect to note on the model is that phonological representations of speech and orthographic representations are ‘bridged’ by the semantic system (i.e. conceptual understanding) that in turn, feeds back information to both of these codes. In the PAPI model, printed words can be read aloud and spoken words *can* be repeated without acessing meaning from the semantic system, but in order for listening or reading comprehension to occur the semantic system must be accessed. The model is also intended to emphasise the importance of phonological mediation of the printed word via lexical or sublexical means as per current understanding of this role. The orthographic input lexicon and phonological mediation module are entwined in a feedback loop with each other, with continual input from semantics. The orthography-to-semantic route must be retained in the model as there is evidence that this route is used when orthography is the *only* method of determining the meaning difference between two single word homophones e.g. ‘meet’ vs. ‘meat’. In this context, the orthographic-to-semantic route may be accessed after phonological mediation has failed to activate semantics without confusion, accounting for the observed delay in the processing of written homophones (Van Orden, 1987; Coltheart et al., 1994).

In the PAPI model, phonologically mediated letters and words do not necessarily access the existing phonological representation in the semantic system. Instead the phonologically mediated information may pass directly to phonological working memory and be read aloud. Therefore, the spoken phonology may not always reflect the status of existing phonological representations. Motor plans can in this way be executed for letters and words without interference from poor quality phonological representations. This may explain why the majority of children with LSR and/or APD do not evince speech disorders nor naming difficulties.

7.9.5 Reading Comprehension and Silent Reading

It is not fully understood whether the effects of PWM on reading comprehension would be the same in a silent reading task compared to reading aloud. As yet, it is difficult to ascertain when an individual is using the lexical route or using a sublexical route for silent reading at any given time. More importantly, the question is whether PWM performance is as deficient in an individual with APD when they are silently sounding and blending or silently phonologically mediating written material? Is it possible to recognise and understand a word in text, yet not be able to phonologically mediate it aloud or assemble it *accurately*? The answer would seem to be yes. Many people will have had the experience of having recognized and understood words that they have read in text yet discover at some later point that they do not pronounce the word according to standard English e.g. mediating ‘status’ to rhyme with ‘gratus’. Would individuals with APD perform better on reading comprehension than predicted from reading accuracy if they were reading silently? It is possible that reading comprehension would still be hindered by an impoverished *phonological input lexicon* and *semantic system* in silent reading, but less by weak PWM in the silent reading task, because external auditory input is absent, as was found in the case of TB reported in section 2.7.3 in the literature review.

Standardised parallel tests of reading comprehension that allow for a comparison between reading aloud and silent reading would be immensely valuable. In the reading aloud condition, if reading errors remain uncorrected by the examiner this would provide a pure test of reading comprehension. A further adjunct to such a study could be a reading-in-noise condition. In this way, it would be possible to gain an understanding of the effects of PWM ability differentially upon silent reading, reading aloud and reading in noise.

Further research is also needed to isolate which aspects of comprehension are more or less affected by specific auditory processing deficits.

7.9.6 Reading Errors

In Study One, the APD group made more errors that lost the meaning of the text compared to the NAPD group. This suggests difficulty with processing meaning while reading, either due to capacity limitations affecting PWM performance, weak semantic representations or poor semantic retrieval. Minor differences between the pattern of errors such as fewer deletions and fewer visual errors in the APD group compared to the NAPD group were not present in the error comparison between the APD group and Average group in Study Two. This is possibly suggestive of visual processing issues in the NAPD group. In contrast, the fewer recasts and decoding errors evident in the APD group in Study One were confirmed and accentuated in Study Two.

In Study two, the APD group made a similar number of errors as the younger Average group and a similar number of errors that lost the intended meaning of the text. However, the APD group made considerably fewer recasts and decoding errors and a considerably greater number of substitution errors. The pattern of reading errors and strategies in the Average reader group might suggest that LSR with APD should be encouraged to recast and decode, however remediation may not be that straightforward if these strategies are hindered by low PWM. The reduced instances of decoding suggest a reluctance to use the letter-sound correspondences during reading which may be a reflection of weak phonological representations, weak phonological retrieval or weak letter-sound associations. It is questionable whether LSR with APD should be remediated to use blending and recasting strategies more often in the presence of PWM deficits. The aim of blending the discrete sounds that correspond to the written symbols is to return the word to its whole sound sequence, to either activate the phonological representation or produce the novel word. If PWM limitations make this task difficult, the result may be an incorrectly sequenced word or different word altogether. However, if the product of letter-to-sound conversion is able to bypass existing phonological representations (as per the PAPI model) in silent reading then silent sound blending may be more efficient for LSR than reading aloud and therefore introducing external auditory input. For the same reason, silent recasting may be more beneficial than recasting aloud. Both strategies could be taught to LSR. In silent reading, decoding may still be immature which will challenge PWM, but blending would be unaffected by processing external input, thus reducing the overall load on PWM.

The diagnostic value of reading error patterns is yet to be determined. The *RAP* analysis would be a good starting point for teachers, speech pathologists and psychologists to evaluate the pattern of reading errors. The results need to be pooled together with observations on naming ability and letter-to-sound correspondence (appropriate to age level) and ideally, oral language ability. Ultimately, it may be possible to distil the findings to specific error types that mark the aetiology of an individual's reading difficulties. For instance, high percentages of substitution errors may be the marker of LSR while effortful naming may be the marker of dyslexia i.e. primarily weak semantics vs. primarily weak phonology. Further, the extent of difficulty is likely to be an indicator of the severity of underlying deficits. This study has profiled the reading errors of students with a diagnosed APD, but in time, the reverse may be possible: to profile reading errors and predict those children for whom an AP assessment is warranted.

Further in-depth analysis of the orthographic environments, syntactic environments, word classes and regularity effects in reading errors may also shed further light on reading error patterns in LSR.

7.9.7 Intervention

Previous longitudinal intervention studies have shown that phonological skills are tractable (Lundberg et al., 1988; Mallen, 1996). A study which trials the benefits of specific strategies (e.g. phonological decoding or recasting) performed silently vs. aloud across two groups of students with APD would be enlightening, compared to a third control group. According to the theory of the Hebb synapse, neurons that regularly fire each other become more efficient at doing so. This is often summarised as 'the neurons that fire together, wire together" (Sejnowski, 2003). Under Hebbian theory, cell assemblies are formed to perform certain functions (Hebb, 1949). Cell assemblies can activate other cortical regions in a specified sequence. Experience of blending sounds aloud may well have established cell assemblies for this purpose. It may be that silent blending is an unnatural route for letter-sound conversion and new cell assemblies would need to be established, but the potential for neural plasticity makes this possibility worthy of exploration.

Finally, but very importantly, rigorous intervention studies which explore the benefits of non-speech auditory training are urgently required. A number of therapeutic programmes that target (speech and non-speech) auditory skills are commercially available, some at high cost, to schools and families offering the promise of improved language and literacy outcomes. Large-scale independent and methodologically robust research studies are vital to determine whether non-speech training can effectively transfer to language and literacy development at rates that can be reliably attributed to the therapy. A few studies to date have made a valuable contribution in this area such as McArthur (2009) and Moore (2007).

In summary, recommendations for further research include:

- Internationally accepted tighter definition of auditory processing disorder;
- Evidence for APD subtyping;
- Investigation of the relationship between frequency discrimination and phonological working memory, integrity of phonological representations and word reading;
- Investigation of the directional relationship between phonological working memory and language deficits, with and without auditory processing deficits;

- Investigation of the role of verb learning in comprehension performance;
- Revision of reading models to incorporate the current understanding of phonological mediation, as per proposed PAPI model in Figure 11;
- Investigation of phonological working memory and reading strategies in silent reading compared to reading aloud;
- Promotion of reading error analyses, such as the *RAP* analysis, as standard classroom practice to guide assistance and intervention for students with reading difficulties;
- Rigorous intervention studies which explore the benefits of non-speech auditory training upon language and reading performance, as a matter of urgency.

Future reading research is of little value unless studies undertake subtyping of less-skilled readers and dyslexic readers into subgroups with primary deficits in phonological decoding, naming, irregular word reading or weak language skills and compare the findings across groups. Further subgroups experiencing visual processing deficits, attention deficits or cognitive deficits may also need to be considered. Of course, in some studies some groups may contain readers with combined deficits, but this needs to be recognised (Walker et al., 2004).

7.10 Clinical Implications

The receptive language and reading performance of the APD group was significantly correlated with weak PWM ability. Evidence of a correlation between pitch pattern processing and PWM was also found in this study. Additionally, poor PWM was implicated in the reading error pattern of the APD group, namely fewer and less successful decoding and recasting attempts.

The implication for both educational and clinical settings is that when a student exhibits a high level of substitution errors (possibly even greater than the number of decoding errors) and a high percentage of errors that are inconsistent with the meaning of the text, exploration of the student's auditory processing abilities may be warranted, in addition to thorough language and phonological assessments. The need for differential diagnosis cannot be over emphasized as reading remediation can only be effective if the cause of reading breakdown is accurately identified and addressed as part of the remediation program.

Weak PWM impedes vocabulary growth (and most likely, vice-versa) in the pre-school years when a child is dependent upon auditory input for linguistic growth. During early literacy education weak PWM also inhibits decoding skills. It is understood that reading experience has reciprocal benefits for linguistic growth, phonological development and PWM (Stanovich, 1986; Metsala, 1999; Brackenbury & Pye, 2005) as displayed in Figure 12. Even though the research supports the involvement of AP deficits in literacy outcomes, the directional flow of the effects requires clarification and therefore, the role of AP deficits has not been included in Figure 12. Further research is needed to impute AP deficits as acting: i. directly on phonology, language or PWM development or ii. in combination with phonological or linguistic deficits, resulting in weak PWM abilities, with subsequent effects on literacy development. If the latter is correct, the implication for intervention is that PWM is most likely to be improved by a focus on AP and linguistic development.

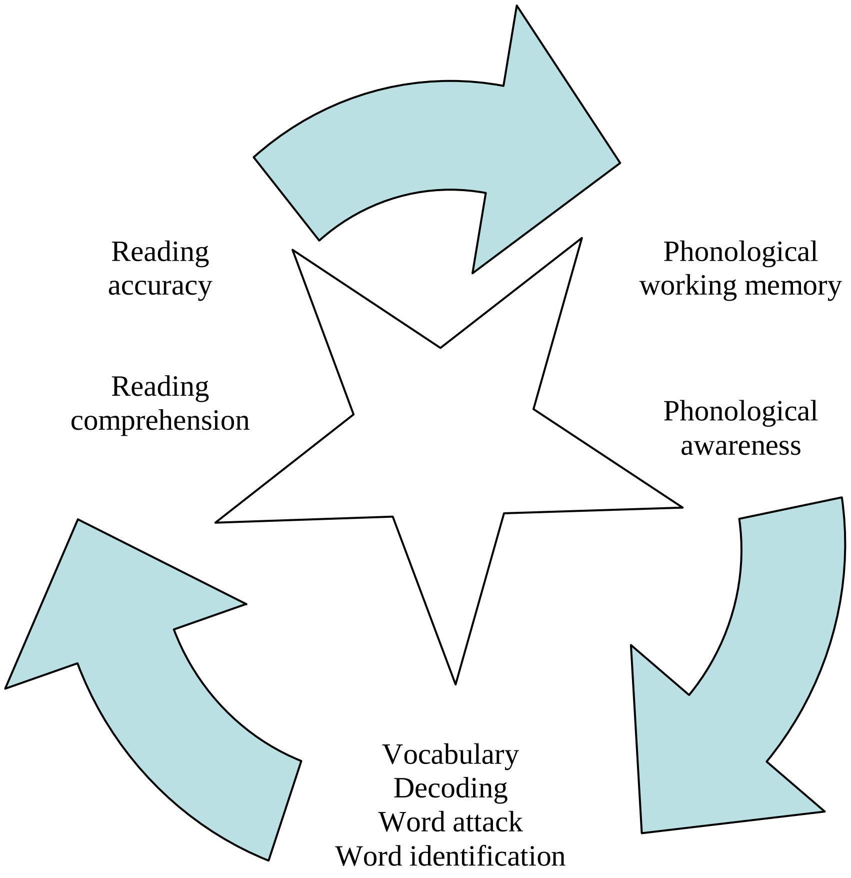


FIGURE 12: The reciprocal nature of reading and component skills

When reading experience is inhibited, linguistic development may be further impeded. Understanding the reciprocal nature of reading experience is particularly relevant for the APD population because reading success may help to compensate for impaired linguistic development. To assist reading development, it is clear that the APD population needs a stronger phonological working memory capacity. Intervention strategies would include:

- assistance to build a strong vocabulary with rich semantic networks e.g. exposure to a wide *oral* vocabulary such that words that appear mainly in text e.g. ‘axis’ but less frequently in speech are presented and explained verbally while words that appear mainly in speech e.g. ‘kerfuffle’ are matched to print;
- assistance to develop more advanced decoding skills e.g. letter chunks-to-sounds;
- practice blending sounds, chunks and syllables in a manageable series that does not overload PWM e.g. two to four sounds/chunks at a time, two syllables at a time in multisyllabic words e.g. ‘yes’+ ‘ter’ = ‘yester’+ ‘day’ = ‘yesterday’;
- practice activating phonological representations using a modified ‘gating’ technique (Bruno et al., 2007). The technique provides greater amounts of a spoken word available to the listener until they are able to activate an acceptable lexical representation e.g. ‘compu’ -> ‘comput’-> ‘computer’;

- regular reading opportunities in a positive environment (e.g. chorused reading) to assist written words to acquire high frequency status;
- explicit development of cognitive strategies for comprehension e.g. schema activation (real world knowledge) from long-term memory, inference, inhibition of irrelevant information, use of the visuo-spatial sketchpad for imagery.

In reference to the PALPA model, the above approaches aim to build a strong *semantic system* to assist word identification and understanding, increase the effectiveness of *letter to sound conversion* for reading accuracy, reduce the load of word length on the *phonological input buffer* (representing PWM) during decoding, develop the *orthographic input lexicon* and establish effective reading comprehension practices using intact components of the central executive. In this way, the achievement of good reading comprehension is seen as the amalgamation of world knowledge, strong receptive language, efficient decoding and rapid word identification. Further research is needed, as discussed in the previous section, to determine whether intervention practices could be developed to enhance the quality of phonological representations in the *phonological input lexicon* for the APD population, such as the discrimination of rising vs. falling pitch in the *Fast ForWord*®Language Program (Gaab, 2007). Current meta-analytic research does not support the efficacy of this intervention approach (McArthur, 2009)

Research is burgeoning in an attempt to understand fully the various causes of reading breakdown. However, beyond the importance of phonological awareness, very few definitive findings have filtered to the seat of education, the classroom setting. This study was concerned with the investigation of the reading abilities of students already diagnosed with an APD. These students showed poorer receptive language and reading abilities, in addition to AP deficits. In particular, standard scores for phonological working memory, receptive vocabulary, reading accuracy and reading comprehension were significantly poorer compared to reading-age matched Average readers. Auditory processing deficits were associated with phonological working memory. In particular, correlations between frequency discrimination and the severity of dichotic listening deficits with phonological working memory were found. In addition, the pattern of reading errors in the LSR readers with APD indicated a preference for whole word substitutions and avoidance of reading strategies which create a load on phonological working memory.

It is anticipated that greater understanding in this area will enable educators to identify students who exhibit the reading errors consistent with this population and consequently, to initiate management and intervention targeted specifically to address the deficits experienced by this population. It is vital to identify both the primary and secondary causes of any reading deficit in order to implement effective non-generic remediation for students with reading difficulty. In a competitive world, there is a pressing need to accurately identify the factors causing reading breakdown to ensure that students are not unnecessarily hindered by reading difficulty within our education system.

CHAPTER EIGHT

Conclusion

The major finding of this study lies in its statistical support of the link between auditory processing and reading development, and in particular reading comprehension, via the effects of phonological working memory and receptive language. AP skills, including dichotic listening abilities, frequency discrimination and temporal order were correlated with PWM performance. It was concluded that firstly, there is a relationship between the interhemispheric transfer of auditory information and phonological working memory. Secondly, it was concluded that there is a relationship between phonological working memory and both receptive language and reading comprehension ability. Whether AP deficits undermine phonological working memory for normal language acquisition or whether AP deficits and linguistic deficits combine to undermine phonological working memory is not determined.

The significantly poorer receptive language ability of the APD group compared to Average readers and the pattern of reading errors indicate that the reading difficulties experienced by the APD group have both a *structural* and *processing* basis as per Crain's (1989) view, explained in the literature review. The less-skilled readers in the APD group are poor comprehenders due to linguistic limitations (structural) *and* poor decoders due to phonological limitations (processing). This study has highlighted at least four possible reasons for reduced reading performance in the APD group. These four reasons are:

- weak phonological working memory, possibly associated with weak phonological representations, affecting receptive language ability
- reduced vocabulary knowledge and listening comprehension, possibly associated with weak semantic representations
- immature decoding, possibly associated with weak phonological processing
- avoidance of the recasting strategy in the reading task, possibly associated with weak phonological working memory

As a group, participants diagnosed with APD were less-skilled readers (LSR) with significantly poorer word attack, word identification, (text) reading accuracy and (text) reading comprehension abilities compared to the reading-age matched Average group. The findings of this study are consistent with an auditory-linguistic integration deficit in the APD group, as shown on dichotic testing and frequency discrimination testing. Poor interhemispheric transfer of auditory input was associated with significantly poorer phonological working memory, receptive language and reading comprehension in the APD group compared to the Average group. Overall severity of AP deficits and PWM correlated significantly with receptive language performance. PWM performance also correlated significantly with reading comprehension performance.

A second major finding showed that right ear performance on the frequency discrimination task correlated with phonological working memory while left ear performance on the frequency discrimination task correlated with word reading performance. Left ear performance on a frequency discrimination task does not require the information to pass back through the corpus callosum for pitch processing in the right hemisphere, but simply to cross at the subcortical level to the right hemisphere. The suggestion is that pitch processing, linguistic processing and phonological skills (letter-sound conversion on the word attack task) within the cortices may play a greater role in reading accuracy performance than the transmission of information along the auditory processing pathways.

The findings support a conclusion that auditory processing deficits may constrain the reliability of phonological representations in long term memory. Phonological representations that are noisy and degraded impair the development of phonology and language with subsequent constraints upon reading development. Novel information, such as unfamiliar vocabulary items will not readily establish a stable phonological representation when the input is unreliable. The trace may decay if it is unstable, or may set up an imprecise representation that is not matched by the next presentation of the same item. That is, pieces of auditory information are lost and the remainder is of poor quality. Lowered vocabulary knowledge is the consequence, as reflected by the significantly weaker receptive vocabulary scores for the APD group in this study.

It is proposed that degraded and unreliable input inhibits the accuracy of phonological representations, efficient phonological working memory and linguistic development even though linguistic potential and the ability to extract information may be normal in the APD group. As a consequence of inhibited linguistic storage, semantic representations are not rich and elaborate either, because these are received primarily via the auditory mode in the pre-literate years. A rich semantic representation is symbolic of an underlying conceptual representation which has a range of associated features including visual, tactile, situational, semantic, morphological, syntactic and pragmatic information including a range of potential meanings (Rastle & Brysbaert, 2006). It is proposed that the impact of AP deficits is limited to phonological and linguistic representations only, and not the other features mentioned. Central executive allocation of attention plus memory processes assist the development of increasingly sophisticated conceptualisations (Walsh, 2007). Within cognitive theory, this study is proposing that AP deficits affect the strategy component, at the integration stage. The load created by inefficient processing exerts an influence on the structural component of capacity, reducing the available capacity for searching, retrieval, semantic analysis and storage. The disturbance to the quantity or quality of the retrieved or constructed phonological representations has ramifications for the access to accurate meaning, resulting in capacity constrained comprehension.

During sentence recall or listening comprehension tasks, the auditory trace in the phonological store will decay rapidly when searching does not readily find a phonologically matched referent. The dynamic auditory input cannot be rapidly coded, sequenced and categorized in accordance with existing phonological and linguistic knowledge embedded in long-term memory. Multiple associated items may be retrieved by the episodic buffer within phonological working memory causing confusion for top-down processes that are attempting to dynamically construct hypotheses regarding the input probabilities. Impaired integration of information within the strategy component of the information processing model leads to reduced functional capacity of phonological working memory. Despite the constant oscillation between bottom-up processing and the expectations of top-down approaches to the input, efficient processing is undermined.

AP performance also changes over time, the result being that AP deficits may affect early phonological and language development, and leave behind weaknesses in these areas even after AP skills have improved on later assessment (Dawes & Bishop, 2009). Longitudinally, it has been shown unequivocally that both phonological and vocabulary knowledge increase exponentially with increased reading competence (Stanovich, 1986; Snowling et al., 2000). Reading provides an alternative input mode of linguistic acquisition, no longer reliant on audition. Not only is the dynamic reading input visual, but by its nature it is a non-fading referent, allowing the reader to spend time acquiring vocabulary by simultaneously establishing a) a semantic representation through inferred meaning and b) an associated phonological representation matched to the orthographic input. Therefore the critical importance of reading proficiency cannot be over-emphasised for the population with APD. Reading competence may be the turning point where the 'drag' of a previously impoverished (auditorily acquired) vocabulary knowledge becomes a rich body of (visually acquired) vocabulary knowledge that enables the reader to 'fly'.

AP deficits have the greatest impact on the phonological store component of phonological working memory while the linguistic deficits have the greatest impact on the phonological loop component of phonological working memory, due to difficulties with retrieval and storage of linguistic information. As the former results in a primacy effect observable on sentence recall tasks and the latter results in a recency effect observable on sentence recall tasks it is not difficult to understand why the combination of deficits is doubly debilitating for efficient information processing. In both cases, performance on nonword repetition tasks would be affected, but for a different reason i.e. phonological store effects on the phonological loop vs. pure rehearsal difficulty in the phonological loop. The result is that unprocessed phonological or linguistic input decays and is then lost: the phenomenon known as forgetting.

The analysis of reading errors in this study showed that the APD group made a greater number of whole word substitutions based on either word shape or meaning/semantics than the reading-age matched Average reader group. Whole word reading errors reflect an earlier developmental reading strategy and are negatively correlated with reading ability (McGuiness, 1997). For instance, to read an irregular word, the item must firstly, be in phonological input lexicon with a corresponding stable phonological representation and secondly, the reader needs decoding skills that are sufficiently advanced in order to access that representation. The reader with APD is likely to be vulnerable on both counts, constraining semantic activation and consequently top-down contextual assistance throughout text reading.

Reading proficiency is the culmination of efficient word identification, phonological decoding skills and language skills in concert with IQ, attention and visual processing abilities. AP deficits may degrade the integrity of the information in the phonological store available to PWM affecting the ability to acquire strong phonological and semantic representations prior to literacy instruction and beyond. Weak PWM and poor phonological representations may also hinder the acquisition of a strong decoding base (letter-to-sound correspondence) during the emergent reading stage. As reading advances weak phonological processing may hinder the ability to develop efficient reading strategies such as mature decoding and recasting strategies that are successful for normally developing readers. Instead, in this study, less-skilled readers with APD unsuccessfully decoded or attempted to guess printed words. It is clear that intervention for this population needs to focus upon the development of stronger vocabulary, stronger phonological distinctions, advanced decoding and memory strategies. In this way, educators can break the internecine relationship between APD, language development and reading ability. The challenge now is to determine the most effective, and possibly unique, reading strategies for this population.

The value of this study's findings in relation to reading errors lies in the applicability of the reading accuracy profile (*RAP)* analysis to the classroom setting. The *RAP* analysis can be used to detect possible underlying auditory or linguistic factors that require further investigation. The analysis of reading errors is also a valuable component of an individual reading remediation programme. It can be used to determine strategies that are currently successful or unsuccessful for the student, targetting development of succesful strategies as a consequence. The *RAP* analysis can also be used to objectively and comprehensively measure progress.

It can be concluded that the reading difficulties experienced by the NAPD group were for reasons other than underlying auditory processing difficulties. It is important to note that AP deficits are not the only cause of phonological processing or reading difficulty. Other factors such as attention difficulties, visual processing difficulty, poor cognitive reasoning and language impairments would also contribute to reading outcomes. In contrast, the difference in performance between the APD group and the reading-age matched Average readers confirmed the role of auditory processing deficits in reading performance for the APD group.

In the wider group of less-skilled readers, there may be a range of causation and therefore the findings of the present study must be limited to the APD group.

It was the aim of this study to clarify the relationship between AP and both receptive language and reading performance. This study has provided evidence of a relationship between AP deficits and phonological working memory, vocabulary, listening comprehension and reading abilities. The importance of considering AP deficits as an aetiological factor in reading research has been underscored by the findings. This study proposes that auditory processing deficits result in decay of, interference to and/or slow processing of phonological and linguistic input. The resultant load constrains the capacity of the system. Reading is a complex and dynamic working memory task, integrating visual, phonological, semantic, syntactic and cognitive information. Individual differences may determine whether greater attention is directed to lower level auditory processing or higher level linguistic processing as a consequence of AP deficits. It is proposed that AP deficits challenge the PWM system, resulting in poorer quality and quantity of storage of both phonological and semantic information in long-term memory. The reader brings these impoverished representations to the reading task. The limitations of PWM also impose on the success of decoding, recasting and comprehension strategies during the reading task.

Participants in the APD group were reading, many within the average range, but as a group they are reading at a sub-optimal level. Seemingly, weaknesses in PWM and language are creating a ‘drag’ on reading performance. Further research is needed in regard to effective intervention targeting AP and PWM abilities, but phonological and language skills are known to be tractable.

Therefore, when a student diagnosed with APD has cognitive abilities within the average range and intact visual and attention processes, there would seem to be no valid reason for reading success to be unattainable. Vitally, input via the reading mode will help to compensate for the constraints upon phonological and linguistic processing imposed by auditory processing limitations. The fulfilment of reading potential is not only of enhanced importance but is also an achievable goal for this subgroup of less-skilled readers.

REFERENCES

Abrams, D., & Kraus, N. (2009). Auditory pathway representations of speech sounds in humans. In J. Katz, L. Medwetsky, R. Burkard & L. Hood (Eds.), *Handbook of Clinical Audiology* (6th ed., pp. 611-626). Philadelphia: Lippincott, Williams & Wilkins.

Adhikari, P. (2006). *Socio-Economic Indexes for Areas: Introduction, use and plans for 2006.* Paper presented at the Census Analysis Conference, Canberra, Australia.

Adlard, A., & Hazan, V. (1998). Speech perception in children with specific reading difficulties. *The Quarterly Journal of Experimental Psychology, 51A*(1), 153-177.

Aguiar, L., & Brady, S. (1991). Vocabulary acquisition and reading ability. *Reading & Writing: An Interdisciplinary Journal, 3*, 413-425.

Ahissar, M., Protopapas, A., Reid, M., & Merzenich, M. M. (2000). Auditory processing parallels reading abilities in adults. *Proceedings of the National Academy of Science, 97*(12), 6832-6837.

Alloway, T. P. (2009). Working memory, but not IQ, predicts subsequent learning in children with learning difficulties. *European Journal of Psychological Assessment, 25*(2), 92-98.

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioural characteristics of children with low working memory. *Child Development, 80*(2), 606-621.

American Management Association (2001). *2001 AMA Survey on Workplace Testing*.

American Speech-Language-Hearing Association (2005). *(Central) auditory processing disorders*. from www.asha.org/members/desk-ref-journals/deskref/default.

Amos, N. E., & Humes, L. E. (1998). SCAN test-retest reliability for first and third-grade children. *Journal of Speech Language and Hearing Research, 41*, 834-845.

Anderson, M. C. (2003). Rethinking interference theory: executive control and the mechanisms of forgetting. *Journal of Memory and Language, 49*, 415-445.

Aparicio, M., Gounot, D., Demont, E., & Metz-Lutz, M. N. (2007). Phonological processing in relation to reading: An fMRI study in deaf readers. *NeuroImage, 35*(3), 1303-1316.

Archibald, L. M. D., & Joanisse, M. F. (2009). On the sensitivity and specificity of nonword repetition and sentence recall to language and memory impairments in children. *Journal of Speech, Language and Hearing Research, 52*, 899-914.

Arnst, D. (1982). Overview of the staggered spondaic word test and the competing environmental sounds test. In D. Arnst & J. Katz (Eds.), *Central Auditory Processing Assessment: The SSW Test Development and Clinical Use*. San Diego,CA: College Hill Press.

August, G. J., & Garfinkel, B. D. (1990). Comorbidity of ADHD and reading disability among clinic-referred children. *Journal of Abnormal Child Psychology, 18*(1).

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*(1), 158-173.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropschology, 8*(4), 485-493.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behaviour, 14*, 575-589.

Baddeley, A. D., & Wilson, B. (1988). Comprehension and working memory: A single case neuropsychological study. *Journal of Memory and Language, 27*(5), 479-498.

Badian, N. A. (1997). Dyslexia and double deficit hypothesis. *Annals of Dyslexia*, *47*, 69-87.

Ball, E. W. (1997). Phonological awareness: Implications for whole language and emergent literacy programs. *Topics in Language Disorder*, *17*(3), 14-26.

Banai, K., Hornickel, J., Skoe, E., Nicol, T. G., Zecker, S., & Kraus, N. (2009). Reading and subcortical auditory function. *Cerebral Cortex, Advanced access*.

Basso, A., Taborelli, A., & Vignolo, L. A. (1978). Dissociated disorders of speaking and writing in aphasia. *Journal of Neurology, Neurosurgery and Psychiatry, 41*, 556-563.

Bell, L., & Perfetti, C. A. (1994). Reading skill: Some adult comparisons. *Journal of Educational Psychology, 86*, 244-255.

Bellis, T. J. (2003). *Assessment and Management of Central Auditory Processing Disorders in the Educational Setting: From Science to Practice.* (2nd ed.). Canada: Singular.

Berlin, C. I., & Lowe, S. S. (1972). Temporal and dichotic factors in central auditory testing. In J. Katz (Ed.), *Handbook of Clinical Audiology*. Baltimore: Williams & Wilkins.

Binder, J. R., Westbury, C. F., McKiernan, K. A., Possing, E. T., & Medler, D. A. (2005). Distinct brain systems for processing concrete and abstract concepts. *Journal of Cognitive Neuroscience, 17*(6), 905-918.

Bishop, D. (2001). Genetic influences on language impairment and literacy problems in children: Same or different? *Journal of Child Psychology and Psychiatry, 42*(2), 189-198.

Bishop, D. (2002). The role of genes in the etiology of specific language impairment. *Journal of Communication Disorders, 35*, 311-328.

Bishop, D., & Adams, C. (1990). A prospective study of the relationship between specific language impairment, phonological disorders and reading retardation. *Journal of Child Psychology and Psychiatry, 31*(7), 1027-1050.

Bishop, D., Carlyon, R. P., Deeks, J. M., & Bishop, S. J. (1999). Auditory temporal processing impairment; neither necessary nor sufficient for causing language impairment in children. *Journal of Speech, Language and Hearing Research, 42*, 1295-1310.

Bishop, D., & McArthur, G. (2005). Individual differences in auditory processing in specific language impairment: A follow-up study using event-related potentials and behavioural thresholds. *Cortex, 41*, 327-341.

Bishop, D., McDonald, D., Bird, S., & Hayiou-Thomas, M. (2009). Children who read words accurately despite language impairment: Who are they and how do they do it? *Child Development, 80*(2), 593-605.

Bitan, T., Burman, D. D., Chou, T.-L., Lu, D., Cone, N. E., Cao, F., et al. (2006). The interaction between orthographic and phonological information in children: An fMRI study. *Human Brain Mapping, 28*(9), 880-891.

Booth, J. R., Bebko, G., Burman, D. D., & Bitan, T. (2007). Children with reading disorder show modality dependent brain abnormalities during semantic tasks. *Neuropsychologica, 45*(4), 775-783.

Booth, J. R., & Burman, D. D. (2005). Neuroimaging to Test Models. In H. W. Catts & A. G. Kamhi (Eds.), *The Connections Between Language and Reading Disabilities*. Mahwah, New Jersey: Allyn & Bacon.

Boothroyd, A. (1982). *Hearing Impairments in Young Children*. Englewood Cliffs, New Jersey: Prentice Hall.

Boothroyd, A. (1997). Auditory development of the hearing child. *Scandinavian Audiology, 26*(supplement 46), 9-16.

Borstrom, I., & Elbro, C. (1997). Prevention of dyslexia in kindergarten: Effects of phoneme awareness training with children of dyslexic parents. In C. Hulme & M. J. Snowling (Eds.), *Dyslexia: Biology, Cognition and Intervention* (pp. 235-253). London: Whurr.

Bowers, P. G., Steffy, R., & Tate, E. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disability. *Reading Research Quarterly, 23*(3), 304-319.

Brackenbury, T., & Pye, C. (2005). Semantic deficits in children with language impairments: Issues for clinical assessment. *Language, Speech and Hearing Services in Schools, 36*(1), 5-16.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read- a causal connection. *Nature, 301*(3), 419-421.

Brady, S., Shankweiler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35*, 345-367.

Breier, J. I., Fletcher, J. M., Foorman, B. R., Klaas, P., & Gray, L. C. (2003). Auditory temporal processing in children with specific reading disability with and without attention deficit/hypercativity disorder. *Journal of Speech Language and Hearing Research, 46*, 31-42.

Bruno, J. L., Manis, F. R., Keating, P., Sperling, A. J., Nakamoto, J., & Seidenberg, M. S. (2007). Auditory word identification in dyslexic and normally achieving readers. *Journal of Experimental Child Psychology, 97*(3), 183-204.

Brunt, M. A. (1972). The Staggered Spondaic Word Test. In J. Katz (Ed.), *Handbook of Clinical Audiology*. Baltimore: Williams & Wilkins.

Brysbaert, M., Grondelaers, S., & Ratinckx, E. (2000). Sentence reading: Do we make use of orthographic cues in homophones? *Acta Psychologica, 105*(1), 31-56.

Brysbaert, M., & Nazir, T. (2005). Visual constraints in written word recognition: Evidence from the optimal viewing position effect. *Journal of Research in Reading, 28*(3), 216-228.

Brysbaert, M., Wijnendaele, I., & De Deyne, D. (2000). Age-of-acquisition effects in semantic processing tasks. *Acta Psychologica, 104*, 215-226.

Bryson, B. (1990). *Mother Tongue*. New York: Penguin.

Butler, K. G. (1983). Language Processing: Selective Attention and Mnemonic Strategies. In E. L. Lasky & J. Katz (Eds.), *Central Auditory Processing Disorders*. Baltimore: University Park Press.

Cacace, A. T., & McFarland, D. J. (1998). Central auditory processing disorder in school-aged children: A critical review. *Journal of Speech, Language and Hearing Research, 41*(2), 355-374.

Cacace, A. T., & McFarland, D. J. (2005). The importance of modality specificity in diagnosing central auditory processing disorder. *American Journal of Audiology, 14*(2), 112-123.

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability and component skills. *Journal of Educational Psychology, 96*(1), 31-42.

Cain, K., Oakhill, J., & Lemmon, K. (2004). Individual differences in the inference of word meanings from context: The influence of reading comprehension, vocabulary knowledge and memory capacity. *Journal of Educational Psychology, 96*(4), 671-681.

Carey, S., & Bartlett, E. (1978). Mapping phonology to a referent; acquiring a single word. *Papers and reports on child language development, 15*, 17-29.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition, 91*, 77-111.

Castles, A., Coltheart, M., Wilson, K., Valpied, J., & Wedgwood, J. (2009). The genesis of reading ability; What helps children learn letter-sound correspondences? *Journal of Experimental Child Psychology, 104*, 68-88.

Cataldo, M. G., & Oakhill, J. (2000). Why are poor comprehenders inefficient searchers? An investigation into the effects of text representation and spatial memory on the ability to locate information in text.

Catts, H., & Kamhi, A. (1999). *Language and Reading Disabilities*. Boston: Allyn and Bacon.

Catts, H. W. (1991a). Early identification of reading disabilities. *Topics in Language Disorder, 12*(1), 1-16.

Catts, H. W. (1991b). Phonological processing deficits and reading disabilities. In A. G. Kamhi & H. W. Catts (Eds.), *Reading Disabilities: A Developmental Language Perspective*. Boston, Massachusetts: Allyn and Bacon.

Catts, H. W., Adlof, S. M., & Weismer, S. E. (2006). Language deficits in poor comprehenders: A case for the simple view of reading. *Journal of Speech, Language and Hearing Research, April*, 278-294.

Catts, H. W., Fey, M. D., Tomblin, J. B., & Zhang, X. (2002). A longitudinal investigation of reading outcomes in children with language impairments. *Journal of Speech Language and Hearing Research, 45*, 1142-1157.

Catts, H. W., Fey, M. D., Zhang, X., & Tomblin, J. B. (2001). Estimating the risk of future reading difficulties in kindergarten children: A research-based model and its clinical implementation. *Language, Speech and Hearing Services in Schools, 32*, 38-50.

Catts, H. W., Hogan, T. P., & Adlof, S. M. (2005). Developmental Changes in Reading and Reading Disabilities. In H. W. Catts & A. G. Kamhi (Eds.), *The Connection Between Language and Reading Disabilities*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Center for the Improvement of Early Reading Achievement; National Institute for Literacy (2003). *Put Reading First: The Research Building Blocks For Teaching Children To Read*. from www.nifl.gov/partnershipsforreading/publications/cierra.pdf.

Cestnick, l., & Jerger, J. (2000). Auditory temporal processing and lexical/nonlexical reading in developmental dyslexics. *Journal of the American Academy of Audiology, 11*(9), 501-513.

Chermak, G. D., & Musiek, F. E. (1997). *Central Auditory Processing Disorders: New Perspectives*. San Diego: Singular Publishing.

Clay, M. M. (2002). *An Observation Survey of Early Literacy Achievement* (2nd ed.). Auckland: Heinemann.

Cohen-Mimran, R., & Sapir, S. (2007). Auditory temporal processing deficits in children with reading disabilities. *Dyslexia, 13*, 175-192.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of Information Processing* (pp. 151-216). London: Academic Press.

Coltheart, M. (2005). Analysing developmental disorders of reading. *Advances in Speech Language Pathology, 7*(2), 49-57.

Coltheart, M., & Leahy, J. (1996). Assessment of lexical and nonlexical reading abilities in children: Some normative data. *Australian Journal of Psychology, 48*(3), 136-140.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC:A dual-route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204-256.

Coltheart, V., Patterson, K., & Leahy, J. (1994). When a ROWS is a ROSE: Phonological effects in written word comprehension. *The Quarterly Journal of Experimental Psychology, 47A*(4), 917-955.

Conrad, R., & Hull, A. J. (1964). Information, acoustic confusion, and memory span. *British Journal of Psychology, 55*, 429-432.

Conti-Ramsden, G., Botting, N., & Faragher, B. (2001). Psycholinguistic markers for specific langauge impairment (SLI). *Journal of Child Psychology and Psychiatry, 42*, 741-748.

Copeland, A. P., & Wisniewski, N. M. (1981). Learning disability and hyperactivity: Deficits in selective attention. *Journal of Experimental Child Psychology, 32*, 88-101.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioural and Brain Sciences, 24*, 87.

Crain, S. (1989). Why poor readers misunderstand spoken sentences. In D. Shankweiler & I. Y. Liberman (Eds.), *Phonology and Reading Disability*: University of Michigan Press.

Cunningham, A. E., & Stanovich, K. E. (1991). Tracking the unique effects of print exposure in children: Associations with vocabulary, general knowledge and spelling. *Journal of Educational Psychology*(83), 264-274.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behaviour, 19*, 450-466.

Dawes, P., & Bishop, D. (2009). Auditory processing disorder in relation to developmental disorders of language, communication and attention: a review and critique. *International Journal of Language and Communication Disorders, 44*(4), 440-465.

De Beni, R., & Palladino, P. (2000). Intrusion errors in working memory tasks: Are they related to reading comprehension ability? *Learning and Individual Differences, 12*, 131-143.

De Beni, R., Palladino, P., Pazzaglia, F., & Cornoldi, C. (1998). Increases in intrusion errors and working memory deficit of poor comprehenders. *The Quarterly Journal of Experimental Psychology, 51*(2), 305-320.

de Jong, P., Bitter, D., van Setten, M., & Marinus, E. (2009). Does phonological encoding occur during silent reading, and is it necessary for orthographic learning? *Journal of Experimental Child Psychology, 104*(3), 267-282.

Deary, I. J. (1995). Auditory inspection time and intelligence: What is the direction of causation? *Developmental Psychology, 31*(2), 237-250.

Department of Education and Children's Services (2003). *Term 3 (Midyear) 2003 Census: Students with Disabilities: Statistical Update*.

Domitz, D. M., & Schow, R. L. (2000). A new CAPD battery - multiple auditory processing assessment: Factor analysis and comparisons with SCAN. *American Journal of Audiology, 9*, 101-111.

Dorland's Pocket Medical Dictionary (1995). (10th ed.). Philadelphia, PA: W.B. Saunders.

Duchan, J. F., & Katz, J. (1983). Language and Auditory Processing: Top Down Plus Bottom Up. In E. L. Lasky & J. Katz (Eds.), *Central Auditory Processing Disorders* (pp. 31-45). Baltimore: University Park Press.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test* (3rd ed.). Minnesota: American Guidance Service.

Dunn, L. M., Whetton, C., & Pintillie, D. (1982). *British Picture Vocabulary Scale*. Windsor, UK: Nfer-Nelson.

Eggermont, J. J. (2001). Between sound and perception: reviewing the search for the neural code. *Hearing Research, 157*(1-2), 1-42.

Elbro, C., Borstrøm, I., & Petersen, D. K. (1998). Predicting dyslexia from kindergarten: the importance of distinctness of phonological representations of lexical items. *Reading Research Quarterly, 33*(1), 36-60.

Ellis, A. W., & Young, A. W. (1988). *Human Cognitive Neuropsychology*. East Sussex, UK: Lawrence Erlbaum Associates.

Enmarker, I., Boman, E., & Hygge, S. (1998). *The effects of noise on memory.* Paper presented at the Noise Effects '98, Sydney, New South Wales, Australia.

Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin and Review, 2*(4), 460-493.

Fawcett, A. J., Nicolson, R. I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia, 46*, 259-283.

Felton, R. H., & Wood, F. B. (1989). Cognitive deficits in reading disability and attention deficit disorder. *Journal of Learning Disabilities, 22*(1), 3-13,22.

Ferretti (2001). Integrating verbs, situation schemas, and thematic role concepts. *Journal of Memory and Language, 44*, 516-547.

Field, L. L., & Kaplan, B. J. (1998). Absence of linkage of phonological coding to chromosome6p23-p21.3 in a large family data set. *American Journal of Human Genetics, 63*, 1448-1456.

Fischer, B., & Hartnegg, K. (2004). On the development of low-level auditory discrimination and deficits in dyslexia. *Dyslexia, 10*, 105-118.

Fletcher, J. M., Shaywitz, S. E., Shankweiler, D., Katz, L., Liberman, I. Y., Stuebing, K. K., et al. (1994). Cognitive profiles of reading disability:Comparisons of discrepancy and low achievement definitions. *Journal of Educational Psychology, 86*(1), 6-23.

Folk, J. R. (1999). Phonological codes are used to access the lexicon during silent reading. *Journal of Experimental Psychology: Learning, Memory and Cognition, 25*(4), 892-906.

Frith, U. (1986). A developmental framework for developmental dyslexia. *Annals of Dyslexia, 36*, 69-81.

Frost, R. (1995). Phonological computation and missing vowels: Mapping lexical involvement in reading. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21*(2), 398-408.

Frost, R., & Ziegler, J. C. (2007). Speech and spelling interaction: The interdependence of visual and auditory word recognition. In M. G. Gaskell (Ed.), *The Oxford Handbook of Psycholinguistics*. Oxford: Oxford University Press.

Gaab, N. (2007). Sound training rewires dyslexic children's brains for reading. Retrieved 28th August 2009, from www.scilearn.com/resources/brain-fitness/sound-training-rewires-childrens-brains-for-reading

Galaburda, A. M., Menard, M. T., & Rosen, G. D. (1994). Evidence for aberrent auditory anatomy in developmental dyslexia. *Proceedings of the National Academy of Science, 91*, 8010-8013.

Gallagher, A., Frith, U., & Snowling, M. J. (2000). Precursors of literacy delay among children at genetic risk of dyslexia. *Journal of Child Psychology and Psychiatry, 41*, 203-213.

Gaskell, M. G. (2007). Statistical and connectionist models of speech perception and word recognition. In M. G. Gaskell (Ed.), *The Oxford Handbook of Psycholinguistics*. Oxford: Oxford University Press.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the words. *Memory and Cognition, 23*(1), 83-94.

Gathercole, S. E. (2007). Working memory and language. In M. G. Gaskell (Ed.), *The Oxford Handbook of Psycholinguistics*. Oxford: Oxford University Press.

Gathercole, S. E., & Baddeley, A. D. (1990). The role of phonological memory in vocabulary acquisition:A study of young children learning new names. *British Journal of Psychology, 81*, 439-454.

Gathercole, S. E., & Baddeley, A. D. (1993). *Working memory and language*. East Sussex, UK: Lawrence Erlbaum Associates Ltd.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40*(2), 177-190.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from National Curriculum Assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*, 1-16.

Gathercole, S. E., Willis, C. S., Baddeley, A. D., & Emslie, H. (1994). The children's test of nonword repetition: A test of phonological working memory. *Memory & Cognition, 2*(2), 103-127.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28*(5), 887-898.

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2002). *Cognitive Neuroscience*. New York: W.W. Norton and Company.

Geffner, D. (2005). What is the role of audition in literacy? [feature, literature review]. *The ASHA Leader, 33*, 8-9.

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16*(3), 430-445.

Ghelani, K., Sidhu, R., Jain, U., & Tannock, R. (2004). Reading comprehension and reading related abilities in adolescents with reading disabilities and attention-deficit/hyperactivity disorder. *Dyslexia, 10*, 364-384.

Ghyselinck, M., Custers, R., & Brysbaert, M. (2004). The effect of age of acquisition in visual word processing: Further evidence for the semantic hypothesis. *Journal of Experimental Psychology: Learning, Memory and Cognition, 30*(2), 550-554.

Gillon, G. (2004). *Phonological Awareness: From Research to Practice*. New York: The Guildford Press.

Gillon, G., & Dodd, B. (1993). The phonological, syntactic and semantic skills of children with specific reading disability. *Australian Journal of Human Comunication Disorders, 21*(1), 86-102.

Gillon, G., & Dodd, B. (1995). The effects of training phonological,semantic and syntactic processing skills in spoken language on reading ability. *Language , Speech and Hearing Services in Schools, 26*(January), 56-68.

Gleitman, L. (1990). The structural sources of verb meaning. *Language Acquisition, 1,* 3-55.

Glushko, R. J. (1979). The organisation and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5*(4), 674-691.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: towards a cross-linguistic theoretical framework. *Dyslexia, 6*, 133-151.

Goswami, U. (2002). Phonology, reading development, and dyslexia: A cross-linguistic perspective. *Annals of Dyslexia, 52*, 141-164.

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading and reading disability. *Remedial and Special Education, 7*(1), 6-10.

Goulandris, N. K. (1996). Assessing Reading and Spelling Skills. In M. J. Snowling & J. Stackhouse (Eds.), *Dyslexia, Speech and Language: A Practitioner's Handbook*. London: Whurr.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recogntion and naming: cross-task comparisons. *Journal of Memory and Language, 35*(623-647).

Green, K. P., & Norrix, L. W. (1997). Acoustic cues to place of articulation and the McGurk effect: The role of release bursts, aspiration and formant transitions. *Journal of Speech, Language and Hearing Research, 40*(3), 646-666.

Guenther, F. H., Nieto-Castanon, A., Ghosh, S. S., & Tourville, J. A. (2004). Representation of sound categories in auditory cortical maps. *Journal of Speech Language and Hearing Research, 47*(1), 46-58.

Hamilton, A. C., & Martin, R. C. (2005). Dissociations among tasks involving inhibition: A single case study. *Cogition, Affective, and Behavioural Neuroscience, 5*(1), 1-13.

Heath, S. M., & Hogben, J. H. (2004). Cost-effective prediction of reading difficulties. *Journal of Speech, Language & Hearing Research, 47*(4), 751-766.

Heath, S. M., Hogben, J. H., & Clark, C. D. (1999). Auditory temporal processing in disabled readers with and without oral language delay. *Journal of Child Psychology and Psychiatry, 40*, 637-647.

Hebb, D. (1949). *The Organisation of Behaviour: A Neuropsychological Theory*. New York: John Wiley and Sons.

Heiervang, E., Stevenson, J., & Hugdahl, K. (2002). Auditory processing in children with dyslexia. *Journal of Child Pyschology and Psychiatry, 43*(7), 931-938.

Hornickel, J., Skoe, E., Nicol, T. G., Zecker, S., & Kraus, N. (2009). Subcortical differentiation of stop consonants relates to reading and speech-in-noise perception. *Proceedings of the National Academy of Science, 106*(31), 13022-13027.

Howard, D., & Best, W. (1996). Developmental phonological dyslexia: Real word reading can be completely normal. *Cognitive Neuropsychology, 13*(6), 887-934.

Hull, M. J. (1999). *Phonological abilities of children diagnosed with and without central auditory processing disorder.* Unpublished Honours, Flinders University, Adelaide.

Hulme, C., & Roodenrys, S. (1995). Practitioner review: Verbal working memory development and its disorders. *Journal of Child Psychology and Psychiatry, 36*(3), 373-398.

Hultquist, A. M. (1997). Orthographic processing abilities of adolescents with dyslexia. *Annals of Dyslexia, 47*, 89-95.

James, D., Van Steenbrugge, W., & Chiveralls, K. (1994). Underlying deficits in language-disordered children with central auditory processing difficulties. *Applied psycholinguistics, 15*, 311-328.

Jerger, J., & Musiek, F. E. (2000). Report of the Consensus Conference on the diagnosis of auditory processing disorders in school-aged children. *Journal of the American Academy of Audiology, 11*, 467-474.

Jerger, S., Martin, R. C., & Jerger, J. (1987). Specific auditory perceptual dysfunction in a learning disabled child. *Ear & Hearing, 8*(2), 78-86.

Johnson, K. L., Nicol, T. G., & Kraus, N. (2005). Brain stem response to speech: A biological marker of auditory processing. *Ear and Hearing, 26*(5), 424-434.

Johnston, R. S., & Anderson, M. (1998). Memory span, naming speed and memory strategies in poor and normal readers. *Memory, 6*, 143-163.

Jones, D. M., Macken, W. J., & Nicholls, A. P. (2004). The phonological store of working memory: is it phonological and is it a store? *Journal of Experimental Psychology: Learning, Memory and Cognition, 30*(3), 656-674.

Jones, M., Plante, E., Tomblin, B. J., & Weismer, S. E. (2005). A functional magnetic resonance imaging investigation of verbal working memory in adolescents with specific language impairment. *Journal of Speech Language and Hearing Research, 48*(2), 405-424.

Jorm, A. F. (1983). Specific reading retardation and working memory: A review. *British Journal of Psychology, 74*, 311-342.

Joseph, J., Noble, K., & Eden, G. (2001). The neurobiological basis of reading. *Journal of Learning Disabilities, 34*, 566-579.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension; Individual differences in working memory. *Psychological Review, 99*(1), 122-149.

Kane, M. J., & Engle, R. W. (2000). Working memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology; Learning, Memory and Cognition, 26*(2), 336-358.

Katz, J. (1977). The Staggered Spondaic Word Test. In R. W. Keith (Ed.), *Central Auditory Dysfunction*. New York,: Grune & Stratton.

Katz, J. (1982). The use of staggered spondaic words for assessing the integrity of the central auditory nervous system. In D. Arnst & J. Katz (Eds.), *Central Auditory Processing Assessment: The SSW Test Development and Clinical Use*. San Diego, CA: College Hill Press.

Katz, J. (2002). *Handbook of Clinical Audiology*. Philadelphia: Lippincott, Williams & Wilkins.

Katz, J., Stecker, N., & Henderson, D. (1992). *Central Auditory Processing; A Transdisciplinary View*. St.Louis: Mosby Year Book.

Katz, J., & Tillery, K. L. (2005). Can central auditory processing tests resist supramodal influences? *American Journal of Audiology, 14*(2), 124-127.

Katz, R. B. (1996). Phonological and semantic factors in the object-naming errors of skilled and less-skilled readers. *Annals of Dyslexia, 46*, 189-208.

Katz, R. B., Healy, A. F., & Shankweiler, D. (1983). Phonetic coding and order memory in relation to reading proficiency: A comparison of short-term memory for temporal and spatial order information. *Applied psycholinguistics, 4*, 229-250.

Katz, R. B., Shankweiler, D., & Liberman, I. Y. (1981). Memory for item order and phonetic recoding in the beginning reader. *Journal of Experimental Child Psychology, 32*, 474-484.

Kay, J., Lesser, R., & Coltheart, M. (1996). Psycholinguistic assessment of language processing in aphasia (PALPA): An introduction. *Aphasiology, 10*(2), 159-180.

Keith, R. W. (1984). Dichotic listening in children. In D. Beasley (Ed.), *Audition in Children; Methods of Study*. San Diego, California: College Hill Press.

Keith, R. W. (1986). *SCAN: A Screening Test for Auditory Processing Disorders*: The Psychological Corporation, Harcourt Brace Jovanovich Inc.

Keith, R. W. (2000). *Random Gap Detection Test*. Ohio, USA: Tartan Products.

Keith, R. W., Rudy, J., Donahue, P. A., & Katbamna, B. (1989). Comparison of SCAN results with other auditory and language measures in a clinical population. *Ear and Hearing, 10*(6), 382-386.

Kent, R. D. (1997). *The Speech Sciences*. San Diego: Singular Publishing.

Kintsch, W., Patel, V. L., & Ericsson, K. A. (1999). The role of long-term working memory in text comprehension. *Psychologia, 42*, 186-198.

Klein, R. M., & Farmer, M. E. (1995). Dyslexia and a temporal processing deficit: A reply to the commentaries. *2, 4*, 515-526.

Kounios, J., & Holcomb, P. J. (1994). Concreteness effects in semantic processing: ERP evidence supporting dual-coding theory. *Journal of Experimental Child Psychology, 20*(4), 804-823.

Kujala, A., Alho, K., Valle, S., Sivonen, P., Ilmoniemei, R. J., Alku, P., et al. (2002). Context modulates processing of speech sounds in the right auditory cortex of human subjects. *Neuroscience Letters, 331*(2), 91-94.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence, 14*, 389-433.

Lamm, O., & Epstein, R. (1997). Dichotic listening in children. *Journal of Experimental Child Psychology, 65*, 24-42.

Lenchner, O., Gerber, M. M., & Routh, D. K. (1990). Phonological awareness tasks as predictors of decoding ability: Beyond segmentation. *Journal of Learning Disabilities, 23*(4), 240-246.

Liberman, I. Y., & Shankweiler, D. (1985). Phonology and the problems of learning to read and write. *Remedial and Special Education*, *6*(6), 8-17.

Lloyd, S. (1998). *The Phonics Handbook* (3rd ed.). Chigwell, UK: Jolly Learning Ltd.

Love, R. J., & Webb, W., G. (1986). *Neurology for the Speech Language Pathologist*. Stoneham, Massachusetts: Butterworths.

Lowe, A. D., & Campbell, R. A. (1965). Temporal discrimination in aphasoid and normal children. *Journal of Speech and Hearing Research, 8*, 313-314.

Lundberg, I. (2002). The child's route into reading and what can go wrong. *Dyslexia, 8*, 1-13.

Lundberg, I., Frost, J., & Petersen, O. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. *Reading Research Quarterly, 33*(Summer), 263-284.

Luo, C. R. (1996). How is word meaning accessed in reading? Evidence from the phonologically mediated interference effect. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22*(4), 883-895.

Lyon, G. R. (1998). Statement to the Committee on Labour and Human Resources: Overview of reading and literacy inititiatives Retrieved 16/5, 2005, from www.nichd.nih.gov/publications/pubs/jeffords.htm

Lyon, G. R. (1999). The NICHD research program in reading development, reading disorders and reading instruction Retrieved 17/3, 2008, from www.ncld.org/research/keys99_nichd.cfm

Lyon, G. R. (2001). Statement before the Subcommittee on Education Reform; Committee on Education and the Workforce. *Measuring Success: Using Assessments and Accountability to Raise Student Achievement* Retrieved 16/5, 2005, from http://edworkforce.house.gov/hearings/107th/edr/account3801/lyon.htm

Mallen, S. (1996). Addressing pre-literacy skills in the preschool setting. *Australian Communication Quarterly*(Autumn), 21-24.

Mallen, S. (1998). *Screen of Phonological Awareness*. South Australia: Hyde Park Press.

Manis, F. R., McBride-Chang, C., Seidenberg, M. S., Keating, P., Doi, L. M., Munson, B., et al. (1997). Are speech perception deficits associated with developmental dyslexia? *Journal of Experimental Child Psychology, 66*, 211-235.

Mann, V., Liberman, I. Y., & Shaywitz, S. E. (1980). Children's memory for sentences and word strings in relation to reading ability. *Memory & Cognition, 8*.

Mann, V., Shankweiler, D., & Smith, S. (1984). The association between comprehension of spoken sentences and early reading ability; The role of phonetic representation. *Journal of child Language, 11*, 627-643.

Marshall, C. M., Snowling, M. J., & Bailey, P. J. (2001). Rapid auditory processing and phonological ability in normal readers and readers with dyslexia. *Journal of Speech, Language and Hearing research, 44*, 925-940.

Martin, F. N. (1986). *Introduction to Audiology*. New Jersey: Prentice-Hall.

Martin, F. N. (1997). The auditory nerve and central auditory pathways. In F. N. Martin (Ed.), *Introduction to Audiology*. Boston, Massachusetts: Allyn and Bacon.

Massaro, D. W. (1975). *Understanding language: An information processing analysis of speech perception, reading and psycholinguistics*. New York: Academic Press.

McArthur, G. (2009). Auditory processing disorders; can they be treated? *Current Opinion in Neurology, 22*, 137-143.

McArthur, G. M., & Bishop, D. (2001). Auditory perceptual processing in people with reading and oral language impairments: Current issues and recommendations. *Dyslexia*, *7*, 150-170.

McCrum, R., Cran, W., & MacNeil, R. (1992). *The Story of English*. New York: Penguin.

McDougall, S. J. P., & Ellis, A. W. (1994). On the problems of comparing dyslexics with other groups of readers (and the quest for a cognitive basis of dyslexia). *Early Child Development and Care*, *10*, 33-49.

McGuiness, D. (1997). Decoding strategies as predictors of reading skill. *Annals of Dyslexia*, *47*, 117-150.

McGuiness, D. (2005). *Language Development and Learning to Read: The Scientific Study of How Language Development Affects Reading Skill*. Massachusetts: The MIT Press.

McNeil, A. M., & Johnston, R. S. (2004). Word length, phonemic, and visual similarity in poor and normal readers. *Memory & Cognition, 32*(5), 687-695.

McQueen, J. M. (2007). Eight questions about spoken word recognition. In M. G. Gaskell (Ed.), *The Oxford Handbook of Pyscholinguistics*. Oxford: Oxford University Press.

Medwetsky, L. (2002a). Central Auditory Processing. In J. Katz (Ed.), *Handbook of Clinical Audiology*. Philadelphia: Lippincott, Williams & Wilkins

Medwetsky, L. (2002b). Central Auditory Processing: A Battery Approach. In J. Katz (Ed.), *Handbook of Clinical Audiology*. Philadelphia: Lippincott, Williams & Wilkins.

Medwetsky, L. (2006). Spoken language processing:A convergent approach to conceptualizing (central) auditory processing. *The ASHA Leader, 11*(8), 6-7,30-31,33.

Metsala, J. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of Educational Psychology, 91*(1), 3-19.

Michael, E. B., Keller, T. A., Carpenter, P. A., & Just, M. A. (2001). fMRI investigation of sentence comprehension by eye and ear:Modality fingerprints on cognitive processes. *Human Brain Mapping, 13*, 239-252.

Ministerial Council on Education Employment Training and Youth Affairs (2006-2008). National Assessment Program Literacy and Numeracy (NAPLAN). Retrieved from www.naplan.edu.au

Ministerial Council on Education Employment Training and Youth Affairs (2008). National Report on Schooling in Australia Retrieved October 19 2009, from www.mceetya.edu.au

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64,* 199-231.

Montgomery, J. W. (2003). Working memory and comprehension in children with specific language impairment: What we know so far. *Journal of Communication Disorders, 36,* 221-231.

Moore, D. (2006). Auditory processing disorder (APD): Definition, diagnosis, neural basis and intervention. *Audiological Medicine, 4,* 4-11.

Moore, D. (2007). Auditory processing disorders:Acquisition and treatment. *Journal of Communication Disorders, 40*(4), 295-304.

Mueller, H., Beck, W., & Sedge, R. (1987). Comparison of efficiency of cortical level speech tests. *Seminars In Hearing, 8*, 279-298.

Munro, N. A., & Lee, K. (2004). *Learning new words - Why is lexical acquisition so hard for children with language disorder?* Paper presented at the International Asociation of Logopedics and Phoniatrics, Brisbane, 2004.

Murray, D. J. (1967). The role of speech responses in short-term memory. *Canadian Journal of Psychology, 21*, 263-276.

Musiek, F. E. (1994). Frequency (pitch) and duration pattern tests. *Journal of the American Academy of Audiology, 5*, 265-268.

Musiek, F. E., Geurink, N. A., & Kietel, S. A. (1982). Test battery assessment of auditory perceptual dysfunction in children. *Laryngoscope, 92,* 251-257.

Musiek, F. E., & Lamb, L. (1994). Central Auditory Assessment: An Overview. In J. Katz (Ed.), *Handbook of Clinical Audiology* (4th ed.). Philadelphia: Williams & Wilkins.

Muter, V., Hulme, C., Snowling, M. J., & Taylor, S. (1997). Segmentation, not rhyming, predicts early progress in learning to read. *Journal of Experimental Child Psychology, 65*, 370-396.

Nation, K. (2005). Connections Between Language and Reading in Children with Poor Comprehension. In H. W. Catts & A. G. Kamhi (Eds.), *The Connections Between Language and Reading Disabilities*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology, 73*, 139-158.

Nation, K., & Cocksey, J. (2009). The relationship between knowing a word and reading it aloud in children's word reading development. *Journal of Experimental Child Psychology, 103*(3), 296-308.

Nation, K., & Snowling, M. J. (1998a). Individual differences in contextual facilitation: Evidence from dyslexia and poor reading comprehension. *Child Development, 4*, 996-1011.

Nation, K., & Snowling, M. J. (1998b). Semantic processing and the development of word-recognition skills: Evidence from children with reading comprehension difficulties. *Journal of Memory and Language, 39,* 85-101.

Nation, K., Snowling, M. J., & Clarke, P. (2007). Dissecting the relationship between language skills and learning to read: Semantic and phonological contributions to new vocabulary learning in children with poor reading comprehension. *Advances in Speech-Language Pathology, 9*(2), 131-139.

National Center for Education Statistics (1998). Retrieved 18th August 2003, from www.nces.ed.gov

Neale, M. D. (1989). *Neale Anlaysis of Reading Ability-Revised British edition*. Windsor, UK: NFER-Nelson.

Neale, M. D. (1999). *Neale Analysis of Reading Ability* (3rd ed.). Melbourne, Australia: ACER Press.

New, B., Ferrand, L., Pallier, C., & Brysbaert, M. (2006). Reexamining the word length effect in visual word recognition: new evidence from the English Lexicon Project. *Psychonomic Bulletin and Review, 13*(1), 45-52.

Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems? *Journal of Speech, Language and Hearing Research, 42*, 925-942.

Norrelgen, F., Lacerda, F., & Forssberg, H. (2002). Temporal resolution in auditory perception and verbal working memory in 15 children with language impairment. *Journal of Learning Disabilities, 35*(6), 539-545.

O'Hara, M., & Johnston, J. (1997). Syntactic bootstrapping in children with specific language impairment. *European Journal of Disorders of Communication, 32*, 189-205.

Oakhill, J., Cain, M., & Bryant, B. R. (2003). The dissociation of word reading and text comprehension: evidence from component skills. *Language and Cognitive Processes, 18*(4), 443-468.

Office of Financial Management (2005). 2005-2006 Budget Statement: New South Wales Treasury.

Organisation for Economic Co-operation and Development [OECD] (2000). Literacy in the Information Age: Final Report of the International Adult Literacy Survey. Retrieved 7th April 2009, from www.oecd.org/dataoecd/48/4/41529765.pdf

Orton, S. T. (1937). *Reading, writing and speech problems in children*. New York: WW Norton & Co.

Patterson, K., & Shewell, C. (1987). Speak and spell: dissociations and word class effects. In M. Coltheart, G. Sarton & R. Job (Eds.), *The Cognitive Neuropsychology of Language*. Hove: Lawrence Erlbaum Associates.

Pennington, B. F., Grossier, D., & Welsh, M. C. (1993). Contrasting cognitive defects in attention deficit hyperactivity disorder vs. reading disability. *Developmental Psychology, 29*, 511-523.

Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language: implications for deaf readers. *Journal of Deaf Studies and Deaf Education, 5*(1), 32-50.

Phillips, D. P. (2002). Central auditory system and central auditory processing disorders: some conceptual issues. *Seminars in Hearing, 23*, 251-261.

Pinheiro, M. L. (1979). *Pitch Pattern Sequence Test*. St.Louis, Missouri: Audiotec.

Pinheiro, M. L., & Musiek, F. E. (1985a). *Assessment of Central Auditory Dysfunction*. Baltimore: Williams and Wilkins.

Pinheiro, S. B., & Musiek, F. E. (1985b). Sequencing and temporal ordering in the auditory system. In S. B. Pinheiro & F. E. Musiek (Eds.), *Assessment of central auditory dysfunction*. Baltimore: Willliams & Wilkins.

Pisoni, D. B., & Levi, S. V. (2007). Representations and representational specificity in speech perception and spoken word recognition. In M. G. Gaskell (Ed.), *The Oxford Handbook of Psycholinguistics*. Oxford: Oxford University Press.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading; Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56-115.

Polk, T., Lacey, H. P., Nelson, J. K., Demiralp, E., Newman, L. I., Krauss, D. A., et al. (2009). The development of abstract letter representations for reading: evidence for the role of context. *Cognitive Neuropsychology, 26*(1), 70-90.

Price, C., Thierry, G., & Griffiths, T. (2005). Speech-specific auditory processing: Where is it? *Trends in Cognitive Sciences, 9*(6), 271-276.

Pring, L., & Snowling, M. J. (1986). Developmental changes in children's use of context in word recognition - an information processing analysis. *Quarterly Journal of Experimental Psychology, 38A*, 395-418.

Prior, M., Sanson, A., Smart, D., & Oberklaid, F. (2000). *Pathways from infancy to adolescence: Australian Temperament project (1983-2000).* Melbourne: Australian Instsitute of Family Studies.

Rack, J. P. (1985). Orthographic and phonetic coding in developmental dyslexia. *British Journal of Psychology, 76*, 325-340.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., et al. (2003). Theories of devlopmental dyslexia: insights from a multiple case study of dyslexic adults. *Brain and Language, 126*, 841-865.

Rastle, K. (2007). Visual word recognition. In M. G. Gaskell (Ed.), *The Oxford Handbook of Psycholinguistics*. Oxford: Oxford University Press.

Rastle, K., & Brysbaert, M. (2006). Masked phonological priming effects in English. *Cognitive Psychology, 53*(2), 97-145.

Raven, J. C., Court, J. H., & Raven, J. (1995). *Manual for Coloured Progressive Matrices*. Oxford, UK: Oxford Psychologists Press.

Reber, A. S. (1985). *Dictionary of Psychology*. Middlesex, England: Penguin Books Ltd.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental Child Psychology, 48*, 270-292.

Roodenrys, S., & Hulme, C. (1991). The development of short-term memory span:separable effects of speech rate and long-term memory. *Journal of Experimental Child Psychology, 56*, 431-442.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything? *Journal of Phonetics, 31*(3), 509-528.

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and nonspeech auditory processing in children with dyslexia? *Journal of Speech, Language and Hearing Research, 44*, 720-736.

Ross, E. D. (1984). Right hemisphere's role in language, affective behaviour and emotion. *Trends in Neuroscience*, 342-346.

Rosson, M. B. (1983). From SOFA to LOUCH: Lexical contributions to pseudoword pronunciation. *Memory and Cognition, 11*(2), 152-160.

Rowe, K. S., Rowe, K. J., & Pollard, J. (2004). *Literacy, behaviour and auditory processing: Building 'fences' at the top of the 'cliff' in preference to 'ambulance services' at the bottom.* Paper presented at the ACER Research Conference Adelaide, South Australia.

Rutter, M., & Yule, W. (1975). The concept of specific reading retardation. *Journal of Child Psychology and Psychiatry, 16*, 181-197.

Sanchez, L. (1989). *Digit Span Test*. Flinders University: unpublished.

Sanchez, L. (2004). *Auditory Processing Disorders: A review of an APD clinical database and the perceptions of children referred for AP assessment.*, presented at Flinders University, South Australia.

Scarborough, H. S. (1990). Very early language deficits in dyslexic children. *Child Development, 61*, 1728-1743.

Scarborough, H. S. (2005). Language and Reading. In H. W. Catts & A. G. Kamhi (Eds.), *The Connections Between Language and Reading Disabilities*. Mahwah, New Jersey: Allyn & Bacon.

Scarborough, H. S., & Dobrich, W. (1994). On the efficacy of reading to preschoolers. *Developmental Review, 14*, 245-302.

Scarborough, H. S., Dobrich, W., & Hager, M. (1991). Preschool literary experience and later reading achievement. *Journal of Learning Disabilities, 24*, 508-511.

Seidenberg, M. S. (1993). A connectionist modeling approach to word recognition and dyslexia. *American Psychological Society, 4*(5), 299-304.

Sejnowski, T. J. (2003). The once and future Hebb synapse. *Canadian Psychology, 44*(1), 17-20.

Semel, E., Wiig, E. H., & Secord, W. (1995). *Clinical Evaluation of Language Fundamentals* (3rd ed.). San Antonio, Texas: The Psychological Corporation, Harcourt Brace and Company.

Service, E. (1998). The effect of word length on immediate serial recall depends on phonological complexity, not articulatory duration. *The Quarterly Journal of Experimental Psychology, 51*(2), 283-304.

Shankweiler, D. (1989). How problems of comprehension are related to difficulties in decoding. In D. Shankweiler & I. Y. Liberman (Eds.), *Phonology and reading disability*: University of Michigan Press.

Shankweiler, D., Liberman, I. Y., Mark, L. S., Fowler, C. A., & Fischer, F. W. (1979). The speech code and learning to read. *Journal of Experimental Psychology: Human Learning and Memory, 5*(6), 531-545.

Shapiro, J., Nix, G. W., & Foster, S. F. (1990). Auditory perceptual processing in reading disabled children. *Journal of Research in Reading, 13*(2), 123-132.

Share, D. L. (1995). Phonological recoding and self-teaching:Sine qua non of reading acquisition. *Cognition, 55*, 151-218.

Share, D. L., Jorm, A. F., MacLean, R., & Matthews, R. (2002). Temporal processing and reading disability. *Reading & Writing: An Interdisciplinary Journal, 15*, 151-178.

Share, D. L., & Leikin, M. (2004). Language impairment at school entry and later reading disability: Connections at lexical versus supralexical levels of reading. *Scientific Studies of Reading, 8*(1), 87-110.

Share, D. L., McGee, R., & Silva, P. A. (1989). IQ and reading progress: A test of the capacity notion of IQ. *Journal of the Academy of Child and Adolescent Psychiatry, 42*, 201-215.

Sharma, M., Purdy, S. C., & Kelly, A. S. (2009). Comorbidity of auditory processing, language and reading disorders. *Journal of Speech Language and Hearing Research, 52*(3), 706-723.

Sharma, M., Purdy, S. C., Newall, P., Wheldall, K., Beaman, R., & Dillon, H. (2006). Electrophysiological and behavioural evidence of auditory processing deficits in children with reading disorder. *Clinical Neuropsychology, 117*(5), 1130-1144.

Shaywitz, S., Escobar, M., Shaywitz, B., Fletcher, J., & Makuch, R. (1992). Evidence that dyslexia may represent the lower tail of a normal distribution of reading ability. *The New England Journal of Medicine, 326*(3), 145-150.

Shaywitz, S. E. (1996). Dyslexia. *Scientific American*, 78-84.

Shillcock, R. C. (2007). Eye movements and visual word recognition. In M. G. Gaskell (Ed.), *The Oxford Handbook of Psycholinguistics*. Oxford: Oxford University Press.

Siegel, L. S. (1988). Evidence that IQ scores are irrelevant to the definition and analysis of reading disability. *Canadian Journal of Psychology, 42*(2), 201-215.

Siegel, L. S. (1993). Phonological processing deficits as the basis of a reading disability. *Developmental Review, 13*, 246-257.

Singer, J., Hurley, R. M., & Preece, J. P. (1998). Effectiveness of central auditory processing tests with children. *American Journal of Audiology, 7*(2), 73-84.

Sloan, C. (1980). Auditory processing disorders and language development. In P. a. S. Levenson, C. (Ed.), *Auditory Processing and Language: Clinical and Research Perspectives* (pp. 101-116). New York: Grune & Stratton.

Smoski, W. J., Brunt, M. A., & Tannahill, J. C. (1992a). Listening Characteristics of childern with central auditory processing disorders. *Language, Speech and Hearing Services in Schools, 23*, 145-152.

Smoski, W. J., Brunt, M. A., & Tannahill, J. C. (1992b). Listening characteristics of children with central auditory processing disorders. *Language, Speech and Hearing Services in Schools, 23*, 145-152.

Snell, R. S. (1987). *Clinical Neuroanatomy for Medical Students*. Boston, Massachusetts: Little, Brown & Company.

Snowling, M. J. (1998). Reading development and its difficulties. *Educational and Child Psychology, 15*, 44-58.

Snowling, M. J. (2000a). *Dyslexia* (2nd ed.). Oxford: Blackwell.

Snowling, M. J. (2000b). Language and literacy skills:Who is at risk and why? In D. V. M. Bishop & L. B. Leonard (Eds.), *Speech and Language Impairment in Children: Causes, Characteristics, Intervention and Outcomes*. East Sussex, UK: Psychology Press.

Snowling, M. J., Bishop, D. V. M., & Stothard, S. (2000). Is preschool language impairment a risk factor for dyslexia in adolescence? *Journal of Child Psychology and Psychiatry, 41*, 587-600.

Snowling, M. J., Goulandris, N., Bowlby, M., & Howell, P. (1986). Segmentation and speech perception in relation to reading skill. *Journal of Experimental Child Psychology, 41*, 489-507.

Snowling, M. J., & Stackhouse, J. (1996). *Dyslexia, Speech and Language: A Practitioner's Handbook*. London: Whurr.

South Australian Government (2004-2005). *South Australian State Budget;Expanding Opportunity: New Literacy and Community Programmes*.

Spreen, O., & Benton, A. L. (1977). *Neurosensory Center Comprehensive Examination for Aphasia*. Victoria, British Colombia, Canada: University of Victoria.

Stackhouse, J. (2000). Barriers to literacy development in children with speech and language difficulties. In D. V. M. a. L. Bishop, L.B. (Ed.), *Speech and Language Impairment In Children; causes, characteristics, intervention and outcomes*. East Sussex, UK: Psychology Press.

Stackhouse, J., & Wells, B. (1997). *Children's speech and literacy difficulties*. London: Whurr Publishers.

Stanley, A. (1999). *Maturation of central auditory processing skills in children with central auditory processing disorder*. Unpublished Honours, Flinders University, Adelaide.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21*(4), 360-406.

Stanovich, K. E. (1988). Exploring the difference between dyslexia and garden-variety poor readers. *Journal of Learning Disabilities, 21*, 590-604.

Stanovich, K. E. (1991). Discrepancy definitions of reading disability: has intelligence led us astray? *Reading Research Quarterly, 16*(1), 7-29.

Stanovich, K. E. (1993). A model for studies of reading disability. *Developmental Review, 13*, 225-245.

Stedman's Medical Dictionary (2005). (28th ed.): Lippincott, Williams & Wilkins.

Stein, J., & Talcott, J. (1999). Impaired neuronal timing in developmental dyslexia- the magnocellular hypothesis. *Dyslexia, 5*, 59-77.

Sternberg, R. J., & Powell, J. S. (1983). Comprehending verbal comprehension. *American Psychologist, 38*, 878-892.

Stokes, S. F., Wong, A. M.-Y., Fletcher, P., & Leonard, L. B. (2006). Nonword repetition and sentence repetition as clinical markers of

SLI: The case of Cantonese. *Journal of Speech, Language and Hearing Research, 49*(2), 219-236.

Stothard, S., & Hulme, C. (1992). Reading comprehension difficulties in children:The role of language comprehension and working memory skills. *Reading and Writing, 4*, 245-256.

Stothard, S., & Hulme, C. (1995). A comparison of phonological skills in children with reading comprehension difficulties and children with decoding difficulties. [secondary]. *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 36*(March), 399-408.

Stothard, S., Snowling, M. J., Bishop, D., Chipchase, B., & Kaplan, C. (1998). Language impaired preschoolers: A follow-up into adolescence. *Journal of Speech, Language and Hearing Research, 41*(2), 407-418.

Strain, E., Patterson, K., & Seidenberg, M. S. (1995). Semantic effects in single word naming. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21*(5), 1140-1154.

Stuart, M. (1999). Getting ready for reading: Early phoneme awareness and phonics tecahing improves reading and spelling in inner-city second langauge learners. *British Journal of Educational Psychology, 69*, 587-605.

Studdert-Kennedy, M., & Mody, M. (1995). Auditory temporal perception deficits in the reading-impaired: A critical review of the evidence. *Psychonomic Bulletin and Review, 2*(4), 508-514.

Swan, D., & Goswami, U. (1997a). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology, 66*, 18-41.

Swan, D., & Goswami, U. (1997b). Picture naming deficits in developmental dyslexia: The phonological representations hypothesis. *Brain and Language, 56*, 334-353.

Swank, L. K., & Catts, H. W. (1994). Phonological awareness and written word decoding. *Language, Speech and Hearing Services in Schools, 25*, 9-14.

Swanson, H. L. (1987). Information Processing Theory and Learning Disabilities: An Overview. *Journal of Learning Disabilities, 20*(1), 3-7.

Swanson, H. L., & O'Connor, R. (2009). The role of working memory and fluency on the reading comprehension of students who are dysfluent readers. *Journal of Learning Disabilities, 42*(6), 548-575.

Talcott, J. B., Witton, C., McClean, M., Hansen, P. C., Rees, A., Green, G. G. R., et al. (1999). Can sensitivity to auditory frequency modulation predict children's phonological and reading skills? *Neuroreport, 10*, 2045-2050.

Tallal, P. (1980). Auditory temporal perception, phonics and reading disabilities in children. *Brain and Language, 9*, 182-198.

Tallal, P., & Stark, R. E. (1982). Perceptual/motor profiles of reading impaired children with or without concomitant oral language deficits. *Annals of Dyslexia, 32*, 163-176.

Taylor, M. M., & Creelman, C. D. (1967). PEST:Efficient estimates on probability functions. *The Journal of the Acoustical Society of America, 41*(4), 782-787.

The Advocacy Institute (2002). *Students with Learning Disabilities: A National Review*. from www.AdvocacyInstitute.org.

The International Dyslexia Association (2002). Definition of dyslexia. Retrieved from www.interdys.org/FactSheets.htm

Thompson, N. C., Cranford, J. L., & Hoyer, E. (1999). Brief tone frequency discrimination by children. *Journal of Speech Language and Hearing Research, 42*, 1061-1068.

Tillery, K. L. (2005). *Characteristics of a large population with and without CAPD.* Paper presented at the Annual Convention of the American Speech-Language-Hearing Association, San Diego,CA.

Tillery, K. L., Katz, J., & Keller, W. D. (2000). Effects of methylpheniadate (Ritalin) on auditory perfomance in children with attention and auditory processing disorders. *Journal of Speech Language and Hearing Research, 43*, 893-901.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities, 27*(5), 276-286.

Towse, J. N., Hitch, G. J., & Hutton, U. (2000). On the interpretation of working memory span in adults. *Memory & Cognition, 28*(3), 341-348.

Tunmer, W. E. (1994). Phonological processing skills and reading remediation. In C. Hulme & M. J. Snowling (Eds.), *Reading development and dyslexia*. London: Whurr.

Tyler, L. K. (1992). *Spoken language comprehension:An experimental approach to disordered and normal processing*. Cambridge, MA: MIT Press.

Vallar, G., & Baddeley, A. D. (1984). Phonological short-term store, phonological processing and sentence comprehension: A neuropsychological case study. *Cognitive Neuropsychology, 1*(2), 121-141.

Vallar, G., & Baddeley, A. D. (1987). Phonological short-term store and sentence processing. *Cognitive Neuropsychology, 4*(4), 417-438.

Van Orden, G. (1987). A ROWS is a ROSE: Spelling, sound and reading. *Memory and Cognition, 15*(3), 181-198.

Van Orden, G. (1991). Phonologic mediation is fundamental to reading. In D. Besner & G. W. Humphreys (Eds.), *Basic Processes in Reading: Visual Word Recognition*. New Jersey: Lawrence Erlbaum Associates.

Vellutino, F., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*(1), 2-40.

Vellutino, F., Scanlon, D., & Spearing, D. (1995). Semantic and phonological coding in poor and normal readers. *Journal of Experimental Child Psychology, 59*, 76-123.

Vellutino, F., Scanlon, D. M., & Lyon, G. R. (2000). Differentiating between difficult- to- remediate and readily remediated poor readers. *Journal of Learning Disabilities, 33*(3), 223-238.

Vellutino, F., Scanlon, D. M., Small, S., & Fanuele, D. P. (2006). Response to intervention as a vehicle for distinguishing between children with and without reading disabilities. *Journal of Learning Disabilities, 39*(2), 157-169.

Vellutino, F., Steger, J., Harding, C., & Phillips, F. (1975). Verbal vs. non-verbal paired-associate learning in poor and normal readers. *Neuropsychologia, 15*, 75-82.

Veuillet, E., Magnan, A., Ecalle, J., Thai-Van, H., & Collet, L. (2007). Auditory processing disorder in children with reading disabilities. *Brain, 130*(11), 2915-2928.

Vogel, S. A. (1975). *Syntactic abilities in normal and dyslexic children*. Baltimore, Md.: University Park Press.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*(2), 192-212.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994a). Development of reading-related phonological processing abilities; New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30*(1), 73-87.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994b). Development of reading-related phonological processing abilities; New evidence of bidirectional causality froma latent variable longitudinal study. *Developmental Psychology, 30*(1), 73-87.

Wake, M., Poulakis, Z., Hughes, E., Carey-Sargent, C., & Rickards, F. (2005). Hearing impairment: A population study of age at diagnosis, severity and language outcomes at 7-8 years. *Archives of Disease in Childhood, 90*(3), 238-244.

Walker, M. M., Shinn, J. B., Cranford, J. L., Givens, G. D., & Holbert, D. (2004). Auditory temporal processing performance of young adults with reading disorders. *Journal of Speech Language and Hearing Research, 45*(3), 598-605.

Walsh, R. (2007). *Defining language and its links to cognition, literacy and chaos theory.* Paper presented at the Speech Pathology Australia National Conference, Sydney, Australia.

Waring, S., Prior, M., Sanson, A., & Smart, D. (1996). Predictors of 'recovery' from reading disability. *Australian Journal of Psychology, 48*(3), 160-166.

Warrier, C., Wong, P., Penhune, V., Zatorre, R., Parrish, T., Abrams, D., et al. (2009). Relating structure to function: Heschl's gyrus and acoustic processing. *The Journal of Neuroscience, 29*(1), 61-69.

Watson, C. S., Kidd, G. R., Horner, D. G., Connell, P. J., Lowther, A., Eddins, D. A., et al. (2003). Sensory, cognitive, and linguistic factors in the early academic performance of elementary school children: The Benton-IU project. *Journal of Learning Disabilities, 36*, 165-197.

Weaver, C. (1994). Reconceptualizing reading and dyslexia. *Journal of Childhood Communication Disorders, 16*(1), 23-25.

Wechsler, D. (1974). *Wechsler Intelligence Scale for Children- Revised*. New York: Psychological Corporation.

Wechsler, D. (2003). *Wechsler Intelligence Scales for Children-Fourth Edition*. San Antonio, Texas: The Psychological Corporation.

Weiler, M. D., Bernstein, J. H., Bellinger, D., & Waber, D. P. (2002). Information processing deficits in children with attention deficit/hyperactivity disorder, inattentive type, and children with reading disability. *Journal of Learning Disabilities, 35*(5), 448-461.

Wendon, L. (2003). *Letterland*. Cambridge: Letterland International Ltd.

Westen, D. (1999). *Psychology: Mind, Brain & Culture* (2nd ed.): John Wiley & Sons.

Wible, B., Nicol, T. G., & Kraus, N. (2005). Correlation between brainstem and cortical auditory processes in normal and language impaired children. *Brain, 128*, 417-423.

Wiederholt, J. L., & Bryant, B. R. (2001). *Gray Oral Reading Tests*. Austin, Texas: Pro-Ed.

Wile, T. L., & Borowsky, R. (2004). What does rapid automatized naming measure? *Brain and Language, 90*, 47-62.

Willeford, J. A. (1977). Assessing central auditory behaviour in children: a test battery approach. In R. W. Keith (Ed.), *Central Auditory Dysfunction*. New York: Grune & Stratton.

Willeford, J. A. (1985). Assessment of central auditory processing disordered in children. In M. L. Pinheiro & F. E. Musiek (Eds.), *Assessment of Central Auditory Dysfunction*. Baltimore: Williams & Wilkins.

Wilson, W. J., Heine, C., & Harvey, L. (2004). Central auditory processing and central auditory processing disorder: fundamental questions and considerations. *The Australian and New Zealand Journal of Audiology, 26*(2), 80-93.

Wilson, W. J., Katz, R. B., Dalgleish, J., & Rix, J. (2007). The Australian Staggered Spondaic Word Test. *The Australian and New Zealand Journal of Audiology, 29*(1), 14-25.

Witton, C., Talcott, J. B., Hansen, P. C., Richardson, A. J., Griffiths, T. D., Rees, A., et al. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. [Research paper]. *Current Biology, 8*(14), 791-797.

Wixson, K. K. (1986). Vocabulary instruction and children's comprehension of basal stories. *Reading Research Quarterly, 21*(3), 317-328.

Wolf, M. (1986). Rapid alternating stimulus naming in the developmental dyslexias. *Brain & Language, 27*, 360-379.

Wolf, M., & Bowers, P. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*(3), 415-438.

Wolf, M., Bowers, P. G., & Biddle, K. (2000). Naming speed processes, timing and reading; A conceptual view. *Journal of Learning Disabilities, 33*(4), 387-407.

Woodcock, R. W. (1998). *Woodcock Reading Mastery Tests- Revised* (Revised ed.). Minnesota: American Guidance Service.

Working Group on Auditory Processing Disorders (2005). from http:/www.asha.org/members/deskref-journals/deskref/default.

Wright, B. A., Lombardino, L. J., King, W. M., Puranik, C. S., Leonard, C. M., & Merzenich, M. M. (1997). Deficits in auditory temporal and spectral resolution in language impaired children. *Nature, 387*(6629), 176-178.

Xavier-Alario, F., De Cara, B., & Ziegler, J. C. (2006). Automatic activation of phonology in silent reading is parallel: Evidence from beginning and skilled readers. *Journal of Experimental Child Psychology, 97*(3), 205-219.

Yopp, H. K. (1992). Developing phonemic awareness in young children. *The Reading Teacher, 45*(9), 696-703.

Yuill, N. M., & Oakhill, J. V. (1991). *Children's problems in text comprehension*. Cambridge: Cambridge University Press.

Yule, W. (1973). Differential prognosis of reading backwardness and specific reading retardation. *British Journal of Educational Psychology, 43*, 244-248.

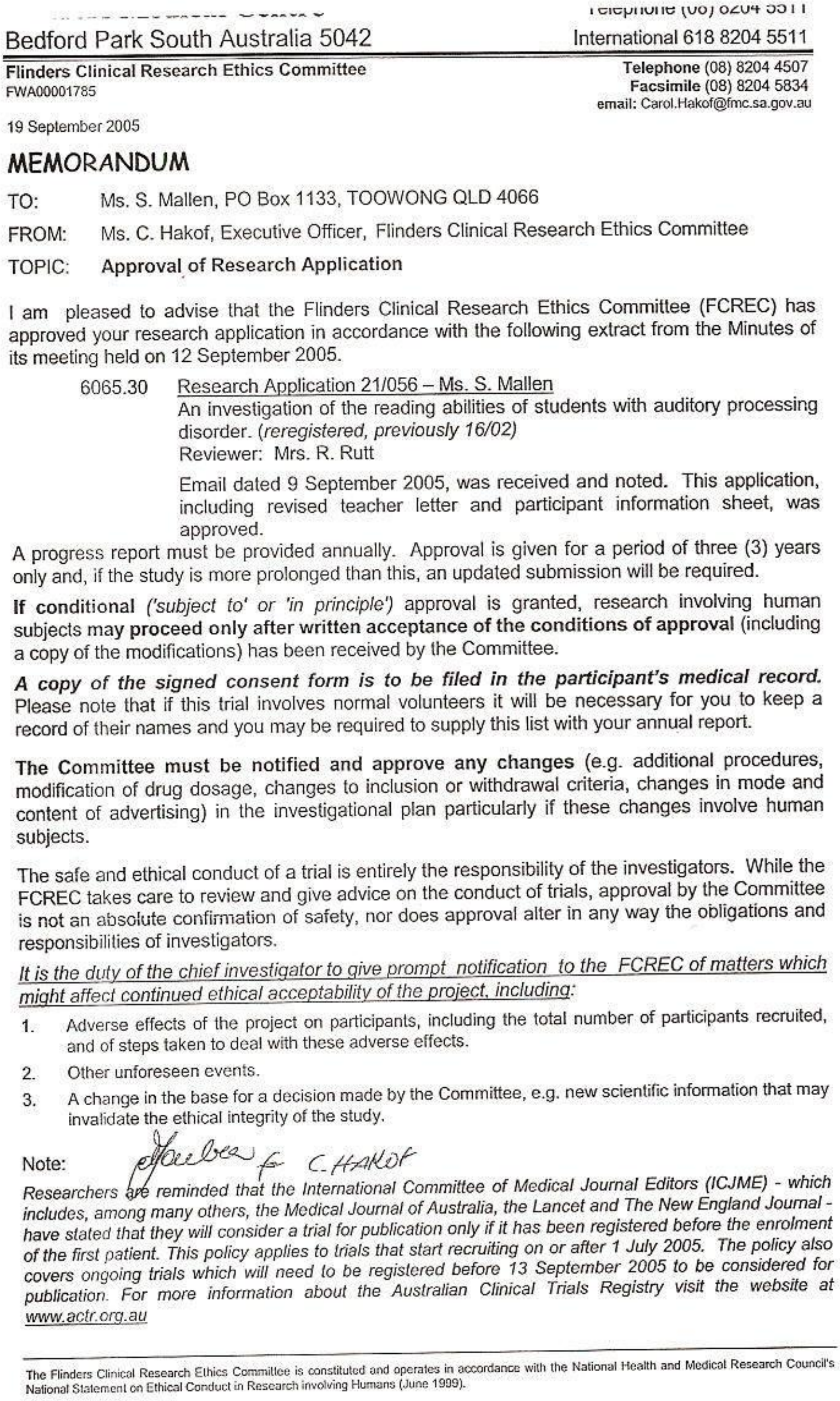
Zattore, R. J., Evans, A. C., & Meyer, E. (1994). Neural mechanisms underlying melodic perception and memory for pitch. *Journal of Neuroscience, 14*(4), 1908-1919.

LIST OF APPENDICES

Study One

Study Two

Appendix A: Ethical Approval: Flinders Clinical Research Ethics Committee



Bedford Park South Australia 5042
International 618 8204 5511

Flinders Clinical Research Ethics Committee
FWA00001785

Telephone (08) 8204 4507
Facsimile (08) 8204 5834
email: Carol.Hakof@fmc.sa.gov.au

19 September 2005

MEMORANDUM

TO: Ms. S. Mallen, PO Box 1133, TOOWONG QLD 4066

FROM: Ms. C. Hakof, Executive Officer, Flinders Clinical Research Ethics Committee

TOPIC: **Approval of Research Application**

I am pleased to advise that the Flinders Clinical Research Ethics Committee (FCREC) has approved your research application in accordance with the following extract from the Minutes of its meeting held on 12 September 2005.

6065.30 Research Application 21/056 – Ms. S. Mallen
An investigation of the reading abilities of students with auditory processing disorder. *(reregistered, previously 16/02)*
Reviewer: Mrs. R. Rutt

Email dated 9 September 2005, was received and noted. This application, including revised teacher letter and participant information sheet, was approved.

A progress report must be provided annually. Approval is given for a period of three (3) years only and, if the study is more prolonged than this, an updated submission will be required.

If conditional *('subject to' or 'in principle')* approval is granted, research involving human subjects may **proceed only after written acceptance of the conditions of approval** (including a copy of the modifications) has been received by the Committee.

A copy of the signed consent form is to be filed in the participant's medical record. Please note that if this trial involves normal volunteers it will be necessary for you to keep a record of their names and you may be required to supply this list with your annual report.

The Committee must be notified and approve any changes (e.g. additional procedures, modification of drug dosage, changes to inclusion or withdrawal criteria, changes in mode and content of advertising) in the investigational plan particularly if these changes involve human subjects.

The safe and ethical conduct of a trial is entirely the responsibility of the investigators. While the FCREC takes care to review and give advice on the conduct of trials, approval by the Committee is not an absolute confirmation of safety, nor does approval alter in any way the obligations and responsibilities of investigators.

It is the duty of the chief investigator to give prompt notification to the FCREC of matters which might affect continued ethical acceptability of the project, including:

1. Adverse effects of the project on participants, including the total number of participants recruited, and of steps taken to deal with these adverse effects.
2. Other unforeseen events.
3. A change in the base for a decision made by the Committee, e.g. new scientific information that may invalidate the ethical integrity of the study.

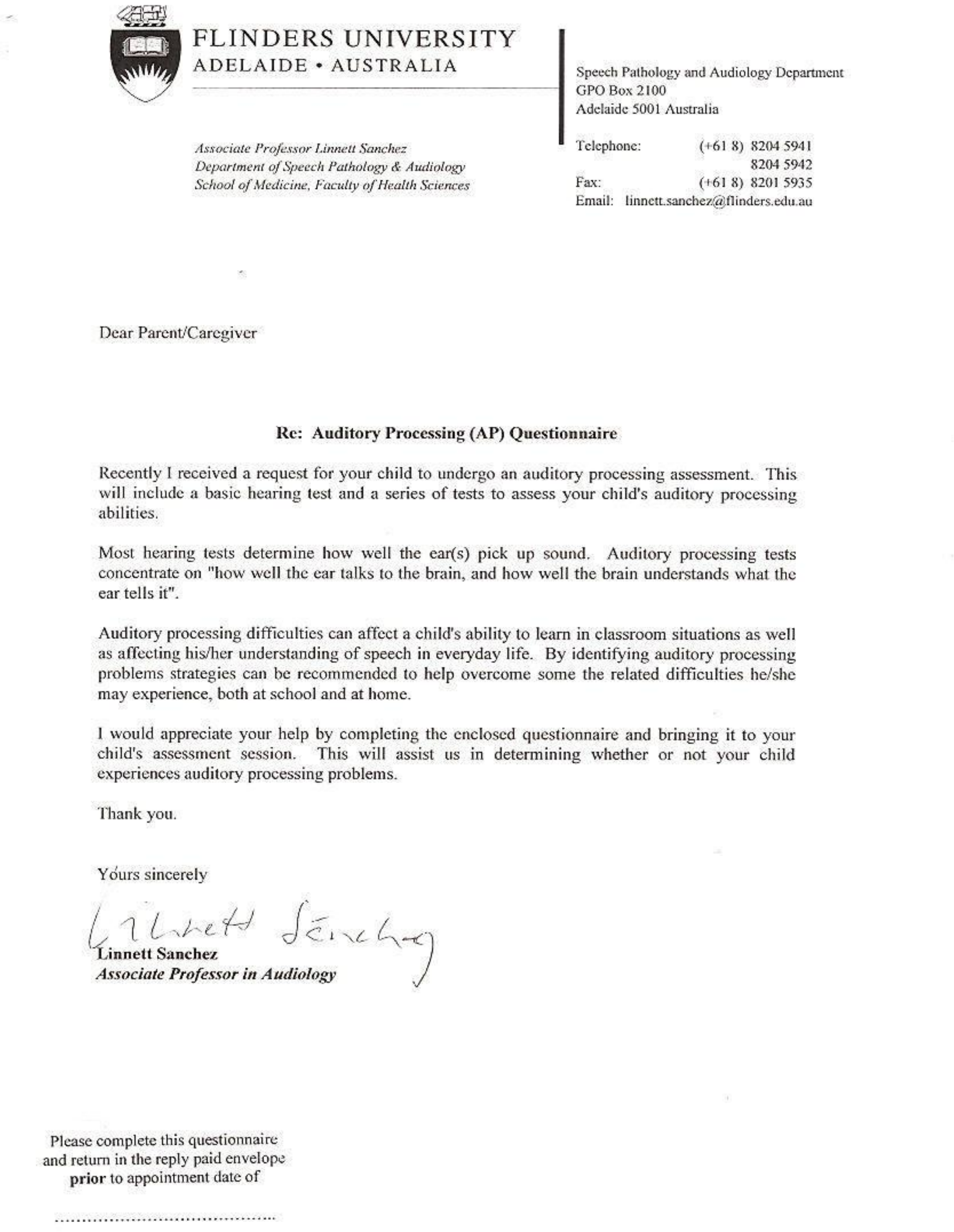
for C. HAKOF

Note:
Researchers are reminded that the International Committee of Medical Journal Editors (ICJME) - which includes, among many others, the Medical Journal of Australia, the Lancet and The New England Journal - have stated that they will consider a trial for publication only if it has been registered before the enrolment of the first patient. This policy applies to trials that start recruiting on or after 1 July 2005. The policy also covers ongoing trials which will need to be registered before 13 September 2005 to be considered for publication. For more information about the Australian Clinical Trials Registry visit the website at www.actr.org.au

---

The Flinders Clinical Research Ethics Committee is constituted and operates in accordance with the National Health and Medical Research Council's National Statement on Ethical Conduct in Research involving Humans (June 1999).

Appendix B: Flinders University Auditory Processing Questionnaire- Parent Version



FLINDERS UNIVERSITY
ADELAIDE • AUSTRALIA

Associate Professor Linnett Sanchez
Department of Speech Pathology & Audiology
School of Medicine, Faculty of Health Sciences

Speech Pathology and Audiology Department
GPO Box 2100
Adelaide 5001 Australia

Telephone: (+61 8) 8204 5941
8204 5942
Fax: (+61 8) 8201 5935
Email: linnett.sanchez@flinders.edu.au

Dear Parent/Caregiver

Re: Auditory Processing (AP) Questionnaire

Recently I received a request for your child to undergo an auditory processing assessment. This will include a basic hearing test and a series of tests to assess your child's auditory processing abilities.

Most hearing tests determine how well the ear(s) pick up sound. Auditory processing tests concentrate on "how well the ear talks to the brain, and how well the brain understands what the ear tells it".

Auditory processing difficulties can affect a child's ability to learn in classroom situations as well as affecting his/her understanding of speech in everyday life. By identifying auditory processing problems strategies can be recommended to help overcome some the related difficulties he/she may experience, both at school and at home.

I would appreciate your help by completing the enclosed questionnaire and bringing it to your child's assessment session. This will assist us in determining whether or not your child experiences auditory processing problems.

Thank you.

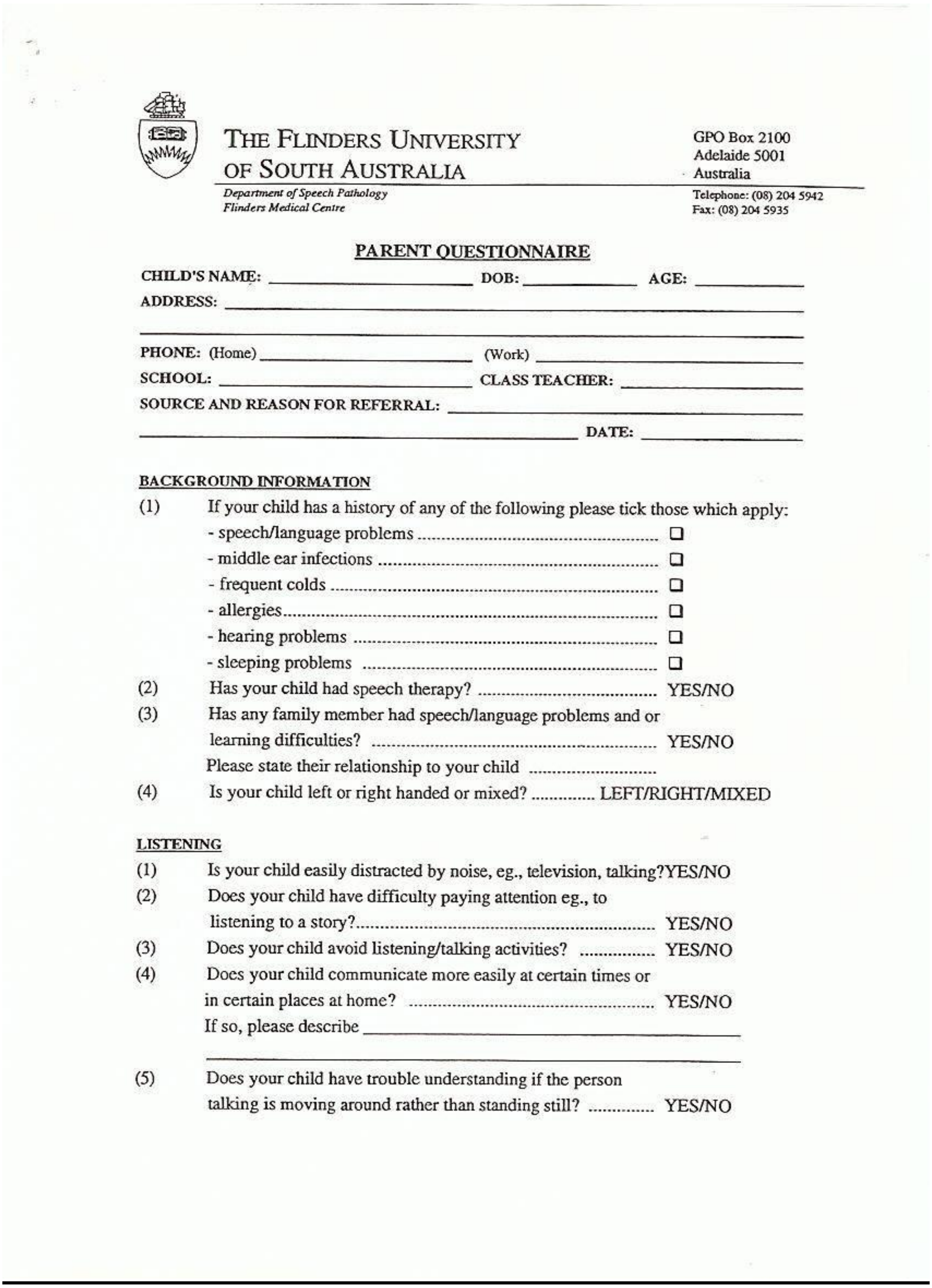
Yours sincerely

Linnett Sanchez

Linnett Sanchez
Associate Professor in Audiology

Please complete this questionnaire
and return in the reply paid envelope
prior to appointment date of

……………………………………



THE FLINDERS UNIVERSITY
OF SOUTH AUSTRALIA

Department of Speech Pathology
Flinders Medical Centre

GPO Box 2100
Adelaide 5001
Australia
Telephone: (08) 204 5942
Fax: (08) 204 5935

PARENT QUESTIONNAIRE

CHILD'S NAME: ______________________ **DOB:** ____________ **AGE:** ____________

ADDRESS: ____

____

PHONE: (Home) ______________________ (Work) ______________________

SCHOOL: ______________________ **CLASS TEACHER:** ______________________

SOURCE AND REASON FOR REFERRAL: ______________________________

______________________________ **DATE:** ______________

BACKGROUND INFORMATION

(1) If your child has a history of any of the following please tick those which apply:
- speech/language problems .... ☐
- middle ear infections .... ☐
- frequent colds .... ☐
- allergies.. ☐
- hearing problems .... ☐
- sleeping problems .... ☐

(2) Has your child had speech therapy? .... YES/NO

(3) Has any family member had speech/language problems and or learning difficulties? .... YES/NO

Please state their relationship to your child ....

(4) Is your child left or right handed or mixed? .... LEFT/RIGHT/MIXED

LISTENING

(1) Is your child easily distracted by noise, eg., television, talking?YES/NO

(2) Does your child have difficulty paying attention eg., to listening to a story?... YES/NO

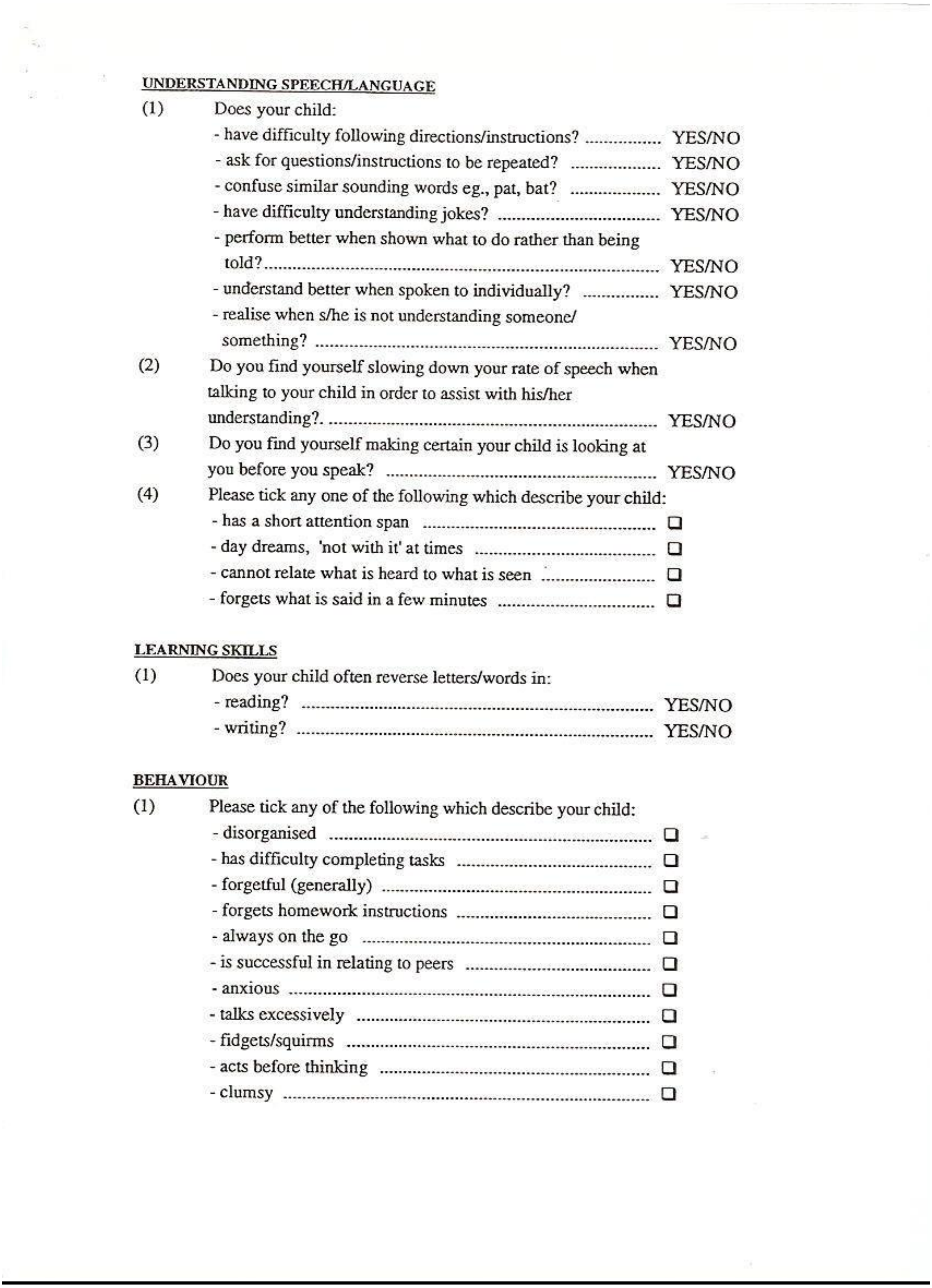
(3) Does your child avoid listening/talking activities? .... YES/NO

(4) Does your child communicate more easily at certain times or in certain places at home? .... YES/NO

If so, please describe ____________________________________

____

(5) Does your child have trouble understanding if the person talking is moving around rather than standing still? .... YES/NO



UNDERSTANDING SPEECH/LANGUAGE

(1) Does your child:
- have difficulty following directions/instructions? .... YES/NO
- ask for questions/instructions to be repeated? .... YES/NO
- confuse similar sounding words eg., pat, bat? .... YES/NO
- have difficulty understanding jokes? .... YES/NO
- perform better when shown what to do rather than being told?.. YES/NO
- understand better when spoken to individually? .... YES/NO
- realise when s/he is not understanding someone/ something? .... YES/NO

(2) Do you find yourself slowing down your rate of speech when talking to your child in order to assist with his/her understanding?. .... YES/NO

(3) Do you find yourself making certain your child is looking at you before you speak? .... YES/NO

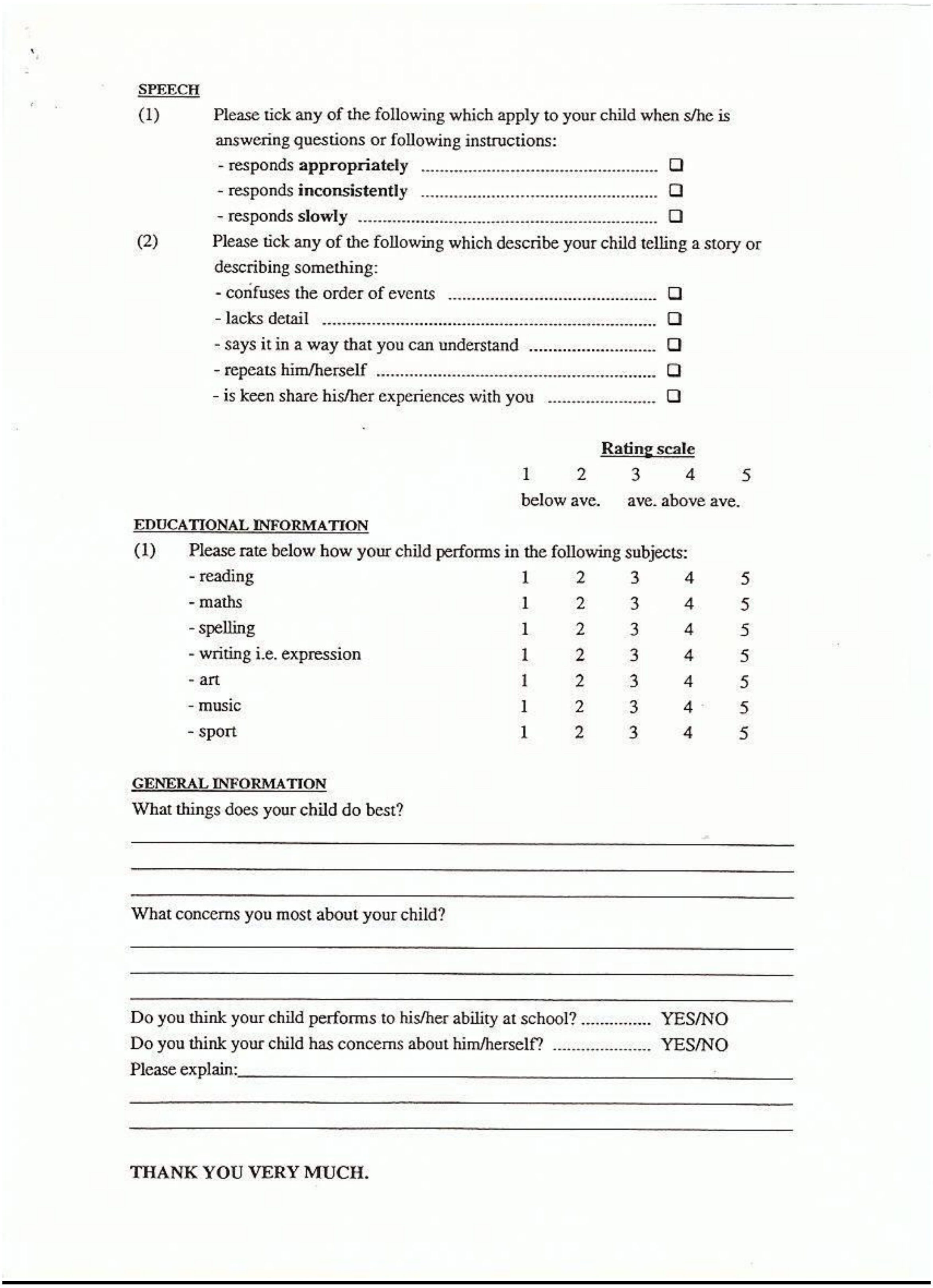
(4) Please tick any one of the following which describe your child:
- has a short attention span .... ☐
- day dreams, 'not with it' at times .... ☐
- cannot relate what is heard to what is seen .... ☐
- forgets what is said in a few minutes .... ☐

LEARNING SKILLS

(1) Does your child often reverse letters/words in:
- reading? .... YES/NO
- writing? .... YES/NO

BEHAVIOUR

(1) Please tick any of the following which describe your child:
- disorganised .... ☐
- has difficulty completing tasks .... ☐
- forgetful (generally) .... ☐
- forgets homework instructions .... ☐
- always on the go .... ☐
- is successful in relating to peers .... ☐
- anxious .... ☐
- talks excessively .... ☐
- fidgets/squirms .... ☐
- acts before thinking .... ☐
- clumsy .... ☐



SPEECH

(1) Please tick any of the following which apply to your child when s/he is answering questions or following instructions:

- responds **appropriately** .... ☐
- responds **inconsistently** .... ☐
- responds **slowly** .... ☐

(2) Please tick any of the following which describe your child telling a story or describing something:

- confuses the order of events .... ☐
- lacks detail .... ☐
- says it in a way that you can understand .... ☐
- repeats him/herself .... ☐
- is keen share his/her experiences with you .... ☐

Rating scale

1 2 3 4 5

below ave. ave. above ave.

EDUCATIONAL INFORMATION

(1) Please rate below how your child performs in the following subjects:

- reading	1	2	3	4	5
- maths	1	2	3	4	5
- spelling	1	2	3	4	5
- writing i.e. expression	1	2	3	4	5
- art	1	2	3	4	5
- music	1	2	3	4	5
- sport	1	2	3	4	5

GENERAL INFORMATION

What things does your child do best?

____

____

____

What concerns you most about your child?

____

____

____

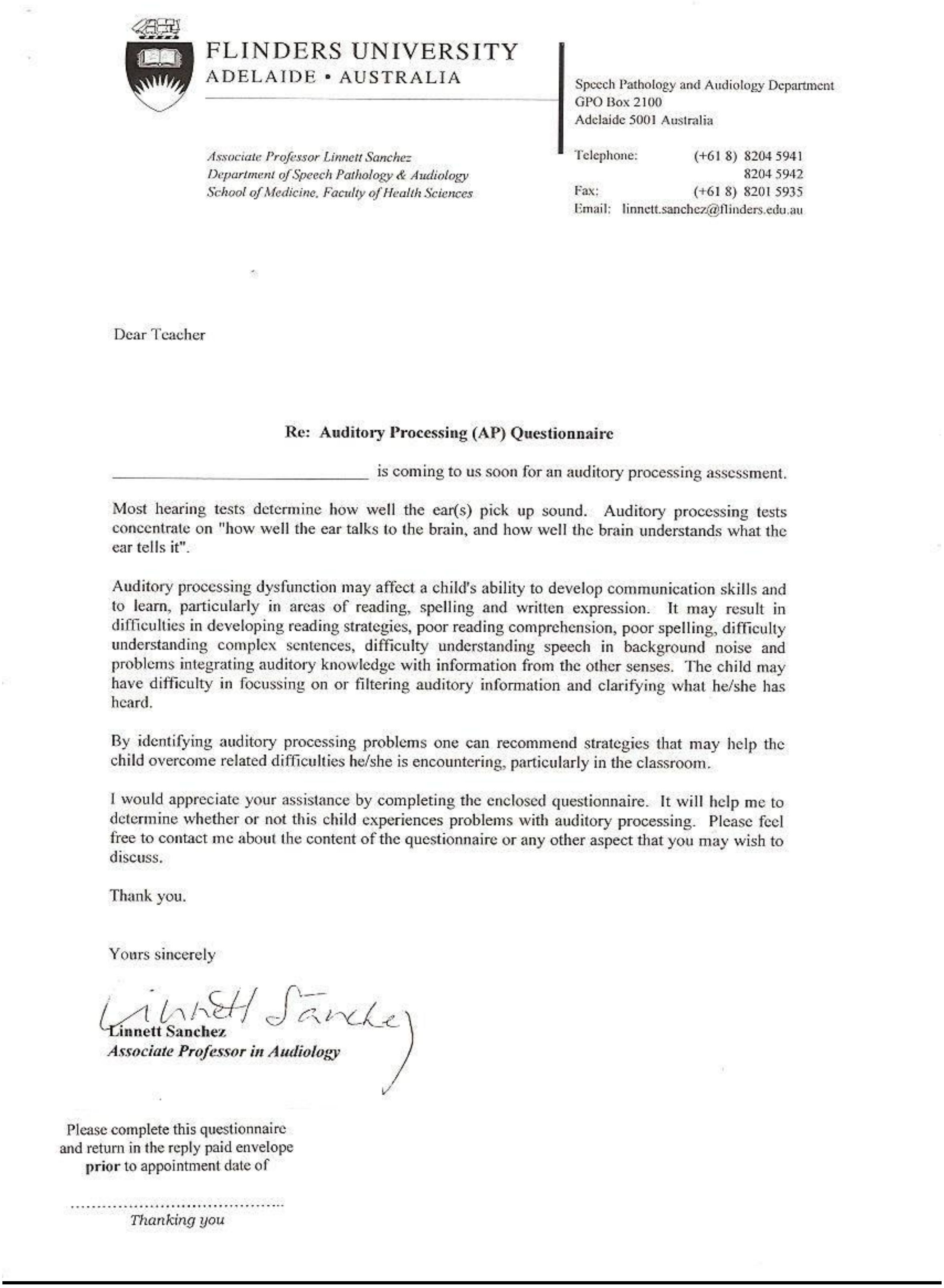
Do you think your child performs to his/her ability at school? .... YES/NO
Do you think your child has concerns about him/herself? .... YES/NO
Please explain:____________________________________

____

____

THANK YOU VERY MUCH.

Appendix C: Flinders University Auditory Processing Questionnaire – Teacher Version



FLINDERS UNIVERSITY
ADELAIDE • AUSTRALIA

Associate Professor Linnett Sanchez
Department of Speech Pathology & Audiology
School of Medicine, Faculty of Health Sciences

Speech Pathology and Audiology Department
GPO Box 2100
Adelaide 5001 Australia

Telephone: (+61 8) 8204 5941
8204 5942
Fax: (+61 8) 8201 5935
Email: linnett.sanchez@flinders.edu.au

Dear Teacher

Re: Auditory Processing (AP) Questionnaire

______________________________ is coming to us soon for an auditory processing assessment.

Most hearing tests determine how well the ear(s) pick up sound. Auditory processing tests concentrate on "how well the ear talks to the brain, and how well the brain understands what the ear tells it".

Auditory processing dysfunction may affect a child's ability to develop communication skills and to learn, particularly in areas of reading, spelling and written expression. It may result in difficulties in developing reading strategies, poor reading comprehension, poor spelling, difficulty understanding complex sentences, difficulty understanding speech in background noise and problems integrating auditory knowledge with information from the other senses. The child may have difficulty in focussing on or filtering auditory information and clarifying what he/she has heard.

By identifying auditory processing problems one can recommend strategies that may help the child overcome related difficulties he/she is encountering, particularly in the classroom.

I would appreciate your assistance by completing the enclosed questionnaire. It will help me to determine whether or not this child experiences problems with auditory processing. Please feel free to contact me about the content of the questionnaire or any other aspect that you may wish to discuss.

Thank you.

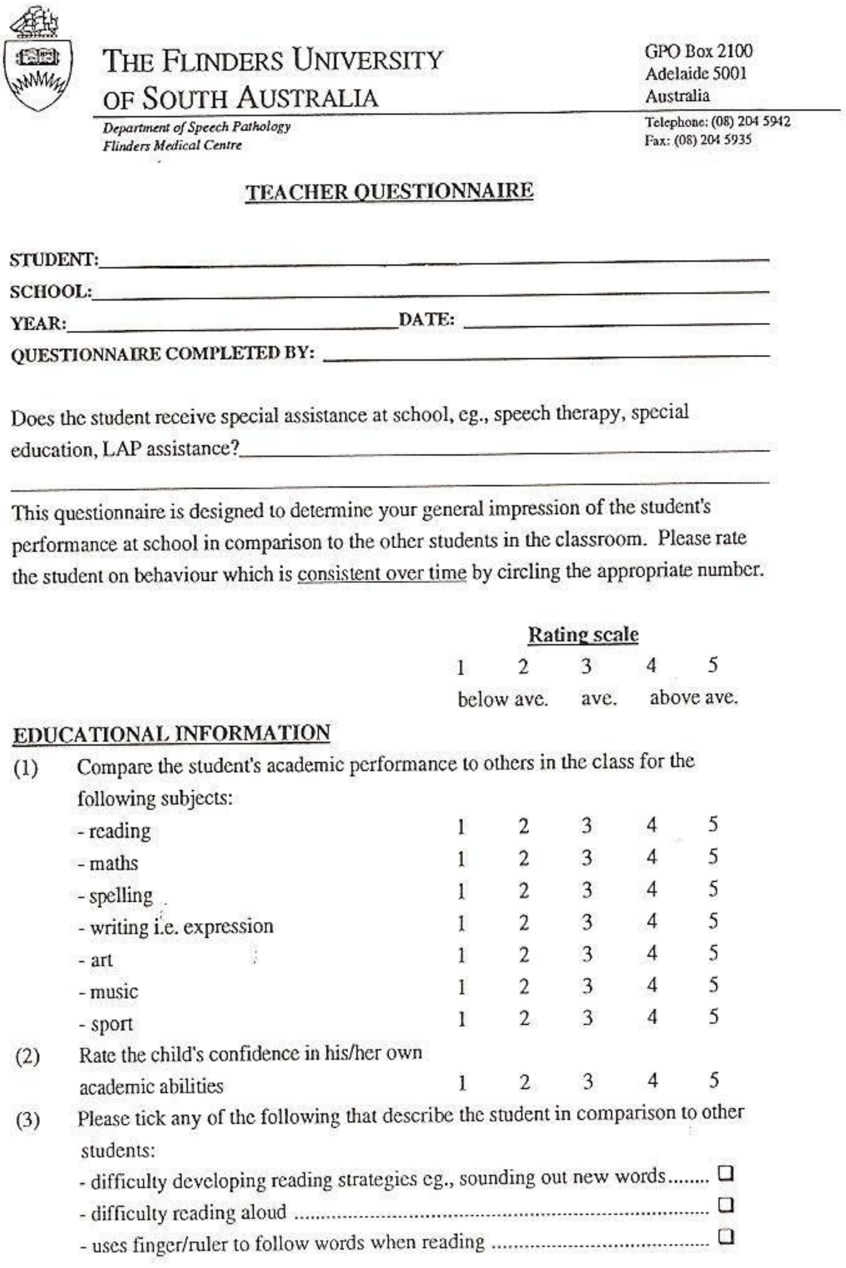
Yours sincerely

Linnett Sanchez

Linnett Sanchez
Associate Professor in Audiology

Please complete this questionnaire
and return in the reply paid envelope
prior to appointment date of

……………………………………
Thanking you



THE FLINDERS UNIVERSITY
OF SOUTH AUSTRALIA
Department of Speech Pathology
Flinders Medical Centre

GPO Box 2100
Adelaide 5001
Australia
Telephone: (08) 204 5942
Fax: (08) 204 5935

TEACHER QUESTIONNAIRE

STUDENT:____

SCHOOL:____

YEAR:____________________ **DATE:** ____________________

QUESTIONNAIRE COMPLETED BY: ____________________________

Does the student receive special assistance at school, eg., speech therapy, special education, LAP assistance?____

____

This questionnaire is designed to determine your general impression of the student's performance at school in comparison to the other students in the classroom. Please rate the student on behaviour which is consistent over time by circling the appropriate number.

Rating scale

	1	2	3	4	5
	below ave.		ave.		above ave.

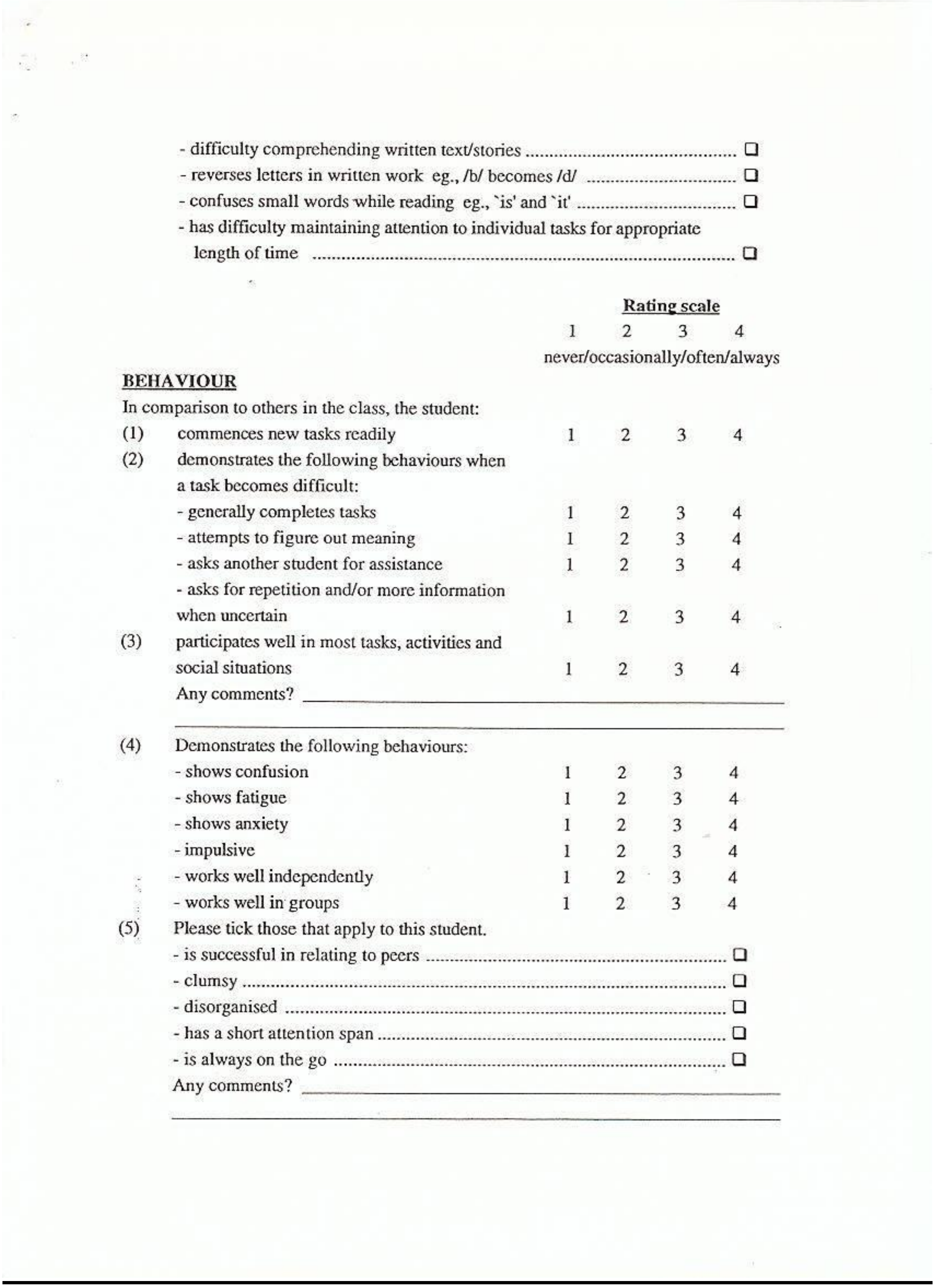
EDUCATIONAL INFORMATION

(1) Compare the student's academic performance to others in the class for the following subjects:

- reading	1	2	3	4	5
- maths	1	2	3	4	5
- spelling	1	2	3	4	5
- writing i.e. expression	1	2	3	4	5
- art	1	2	3	4	5
- music	1	2	3	4	5
- sport	1	2	3	4	5
(2) Rate the child's confidence in his/her own academic abilities	1	2	3	4	5

(3) Please tick any of the following that describe the student in comparison to other students:

- difficulty developing reading strategies eg., sounding out new words........ ☐
- difficulty reading aloud .... ☐
- uses finger/ruler to follow words when reading .... ☐



- difficulty comprehending written text/stories .... ☐
- reverses letters in written work eg., /b/ becomes /d/ .... ☐
- confuses small words while reading eg., `is' and `it' .... ☐
- has difficulty maintaining attention to individual tasks for appropriate length of time .... ☐

	Rating scale			
	1	2	3	4
	never/	occasionally/	often/	always
BEHAVIOUR				
In comparison to others in the class, the student:				
(1) commences new tasks readily	1	2	3	4
(2) demonstrates the following behaviours when a task becomes difficult:				
- generally completes tasks	1	2	3	4
- attempts to figure out meaning	1	2	3	4
- asks another student for assistance	1	2	3	4
- asks for repetition and/or more information when uncertain	1	2	3	4
(3) participates well in most tasks, activities and social situations	1	2	3	4

Any comments? ____

____

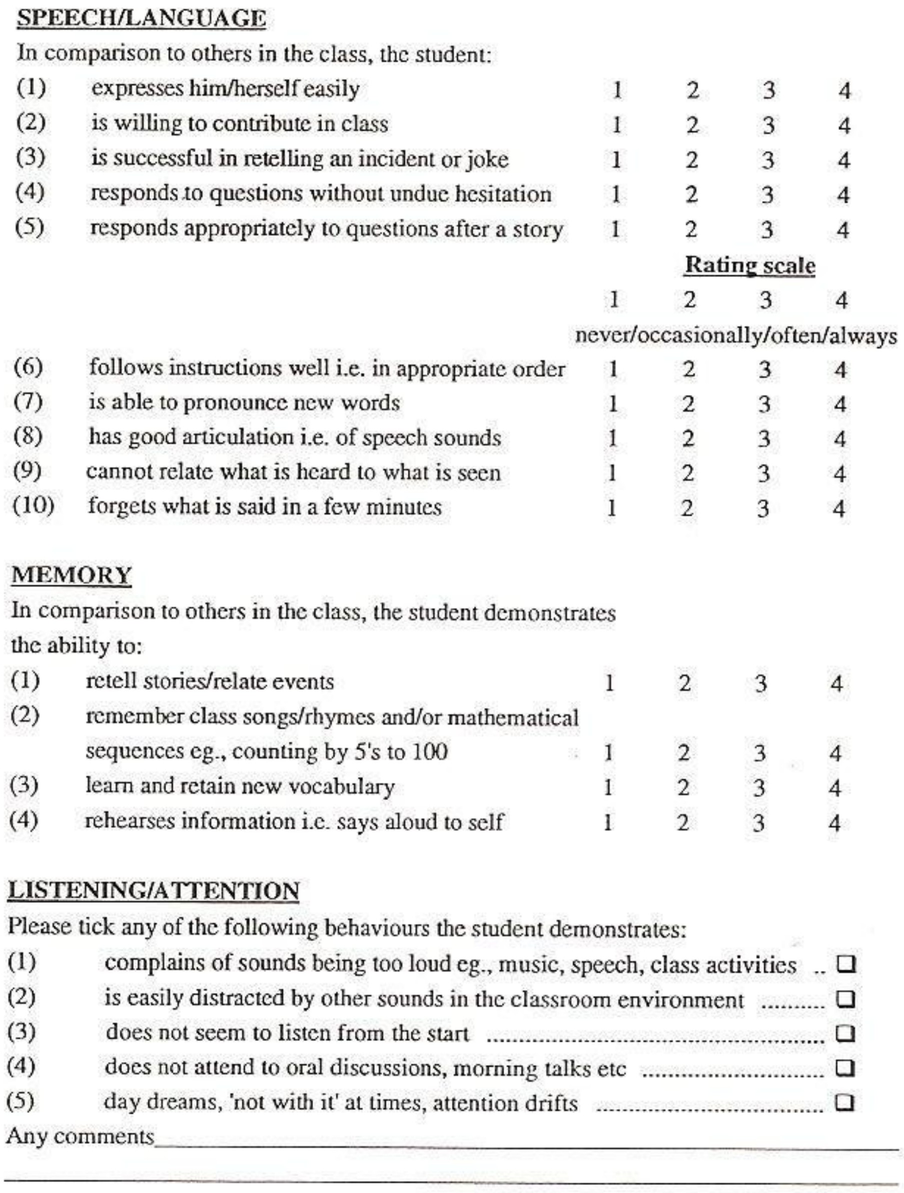
(4) Demonstrates the following behaviours:				
- shows confusion	1	2	3	4
- shows fatigue	1	2	3	4
- shows anxiety	1	2	3	4
- impulsive	1	2	3	4
- works well independently	1	2	3	4
- works well in groups	1	2	3	4

(5) Please tick those that apply to this student.

- is successful in relating to peers .... ☐
- clumsy .... ☐
- disorganised .... ☐
- has a short attention span .... ☐
- is always on the go .... ☐

Any comments? ____

____



SPEECH/LANGUAGE

In comparison to others in the class, the student:

(1)	expresses him/herself easily	1	2	3	4
(2)	is willing to contribute in class	1	2	3	4
(3)	is successful in retelling an incident or joke	1	2	3	4
(4)	responds to questions without undue hesitation	1	2	3	4
(5)	responds appropriately to questions after a story	1	2	3	4

Rating scale

1 2 3 4

never/occasionally/often/always

(6)	follows instructions well i.e. in appropriate order	1	2	3	4
(7)	is able to pronounce new words	1	2	3	4
(8)	has good articulation i.e. of speech sounds	1	2	3	4
(9)	cannot relate what is heard to what is seen	1	2	3	4
(10)	forgets what is said in a few minutes	1	2	3	4

MEMORY

In comparison to others in the class, the student demonstrates the ability to:

(1)	retell stories/relate events	1	2	3	4
(2)	remember class songs/rhymes and/or mathematical sequences eg., counting by 5's to 100	1	2	3	4
(3)	learn and retain new vocabulary	1	2	3	4
(4)	rehearses information i.e. says aloud to self	1	2	3	4

LISTENING/ATTENTION

Please tick any of the following behaviours the student demonstrates:

(1) complains of sounds being too loud eg., music, speech, class activities .. ☐

(2) is easily distracted by other sounds in the classroom environment .... ☐

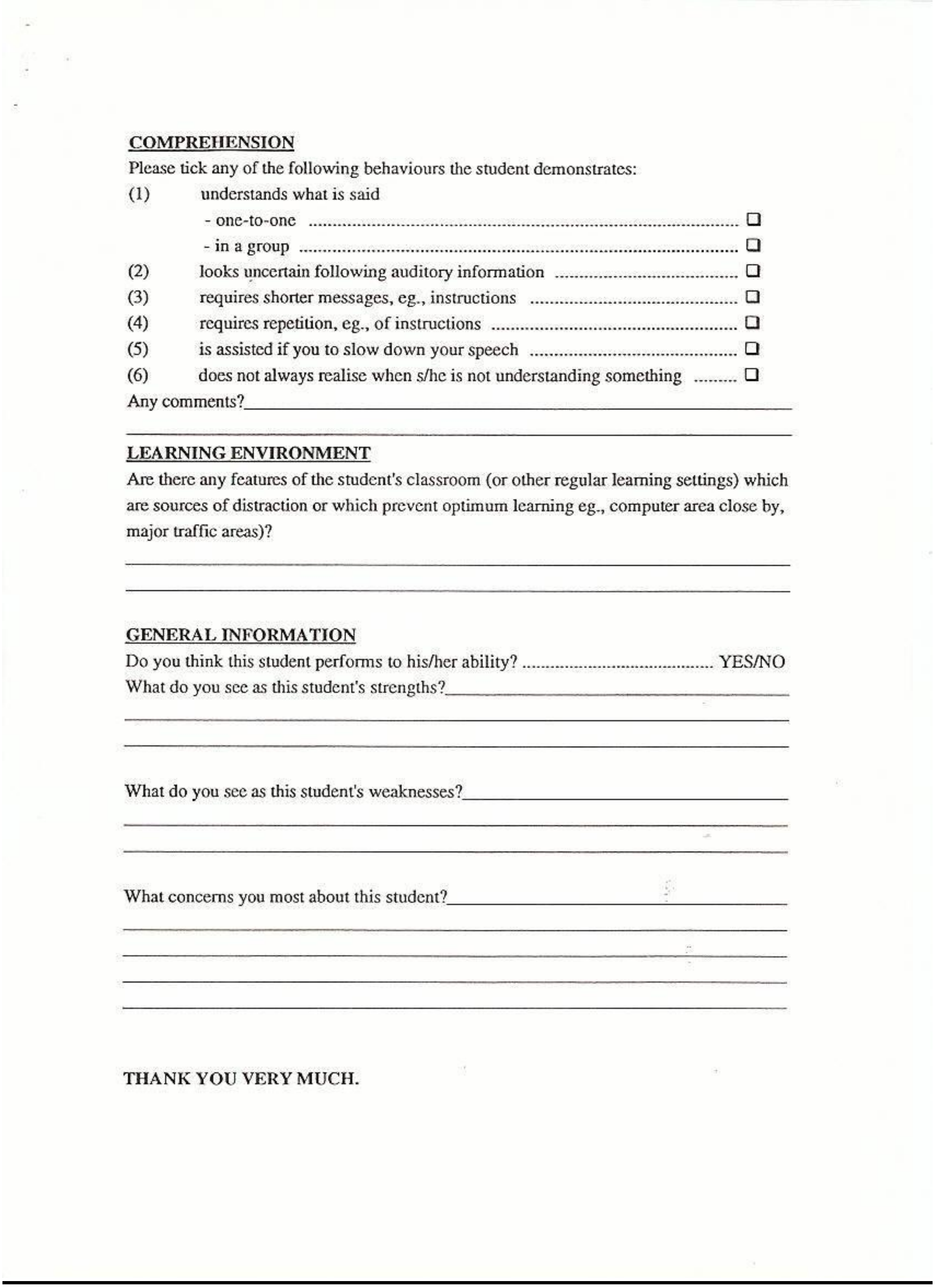
(3) does not seem to listen from the start .... ☐

(4) does not attend to oral discussions, morning talks etc .... ☐

(5) day dreams, 'not with it' at times, attention drifts .... ☐

Any comments____

____



COMPREHENSION

Please tick any of the following behaviours the student demonstrates:

(1) understands what is said
  - one-to-one .... ☐
  - in a group .... ☐

(2) looks uncertain following auditory information .... ☐

(3) requires shorter messages, eg., instructions .... ☐

(4) requires repetition, eg., of instructions .... ☐

(5) is assisted if you to slow down your speech .... ☐

(6) does not always realise when s/he is not understanding something .... ☐

Any comments?

LEARNING ENVIRONMENT

Are there any features of the student's classroom (or other regular learning settings) which are sources of distraction or which prevent optimum learning eg., computer area close by, major traffic areas)?

GENERAL INFORMATION

Do you think this student performs to his/her ability? .... YES/NO

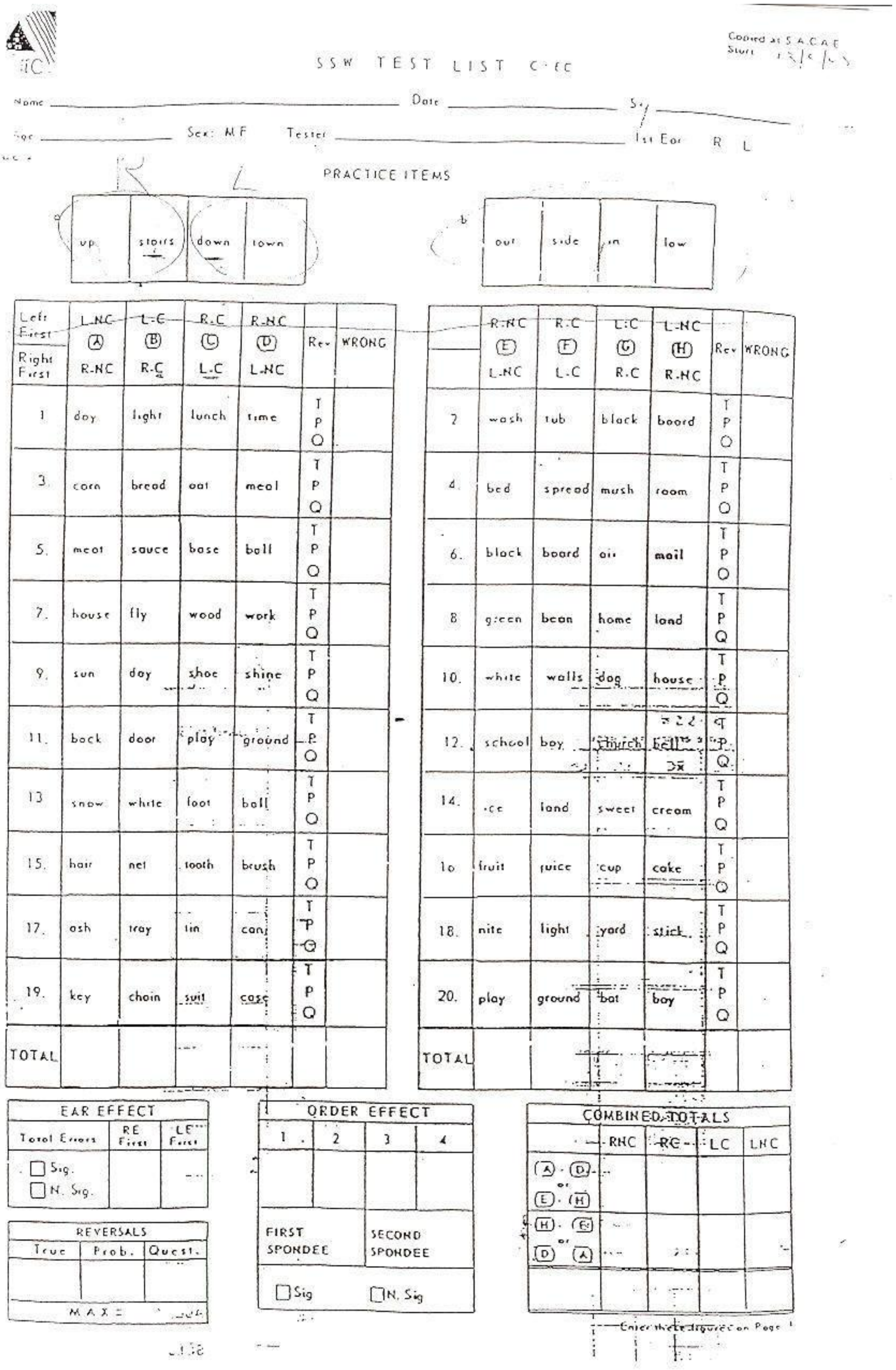
What do you see as this student's strengths?

What do you see as this student's weaknesses?

What concerns you most about this student?

THANK YOU VERY MUCH.

Appendix D: Flinders University Auditory Processing Battery –Score Forms (1 of 4)



Copied at S.A.C.A.E.
Start 13/6/85

SSW TEST LIST C-EC

Name ______________________ Date ______________ S/ ______________
Age ____________ Sex: M F Tester ______________________ 1st Ear R L

PRACTICE ITEMS

R L

up	stairs	down	town

out	side	in	low

Left First Right First	L-NC Ⓐ R-NC	L-C Ⓑ R-C	R-C Ⓒ L-C	R-NC Ⓓ L-NC	Rev	WRONG
1	day	light	lunch	time	T P Q	
3.	corn	bread	oat	meal	T P Q	
5.	meat	sauce	base	ball	T P Q	
7.	house	fly	wood	work	T P Q	
9.	sun	day	shoe	shine	T P Q	
11.	back	door	play	ground	T P Q	
13	snow	white	foot	ball	T P Q	
15.	hair	net	tooth	brush	T P Q	
17.	ash	tray	tin	can	T P Q	
19.	key	chain	suit	case	T P Q	
TOTAL						

	R-NC Ⓔ L-NC	R-C Ⓕ L-C	L-C Ⓖ R-C	L-NC Ⓗ R-NC	Rev	WRONG
2	wash	tub	black	board	T P Q	
4.	bed	spread	mush	room	T P Q	
6.	black	board	air	mail	T P Q	
8	green	bean	home	land	T P Q	
10.	white	walls	dog	house	T P Q	
12.	school	boy	church	bell	T P Q	
14.	ice	land	sweet	cream	T P Q	
16	fruit	juice	cup	cake	T P Q	
18.	nite	light	yard	stick	T P Q	
20.	play	ground	bat	boy	T P Q	
TOTAL						

EAR EFFECT

Total Errors	RE First	LE First
☐ Sig. ☐ N. Sig.		

REVERSALS

True	Prob.	Quest.
MAX =		

ORDER EFFECT

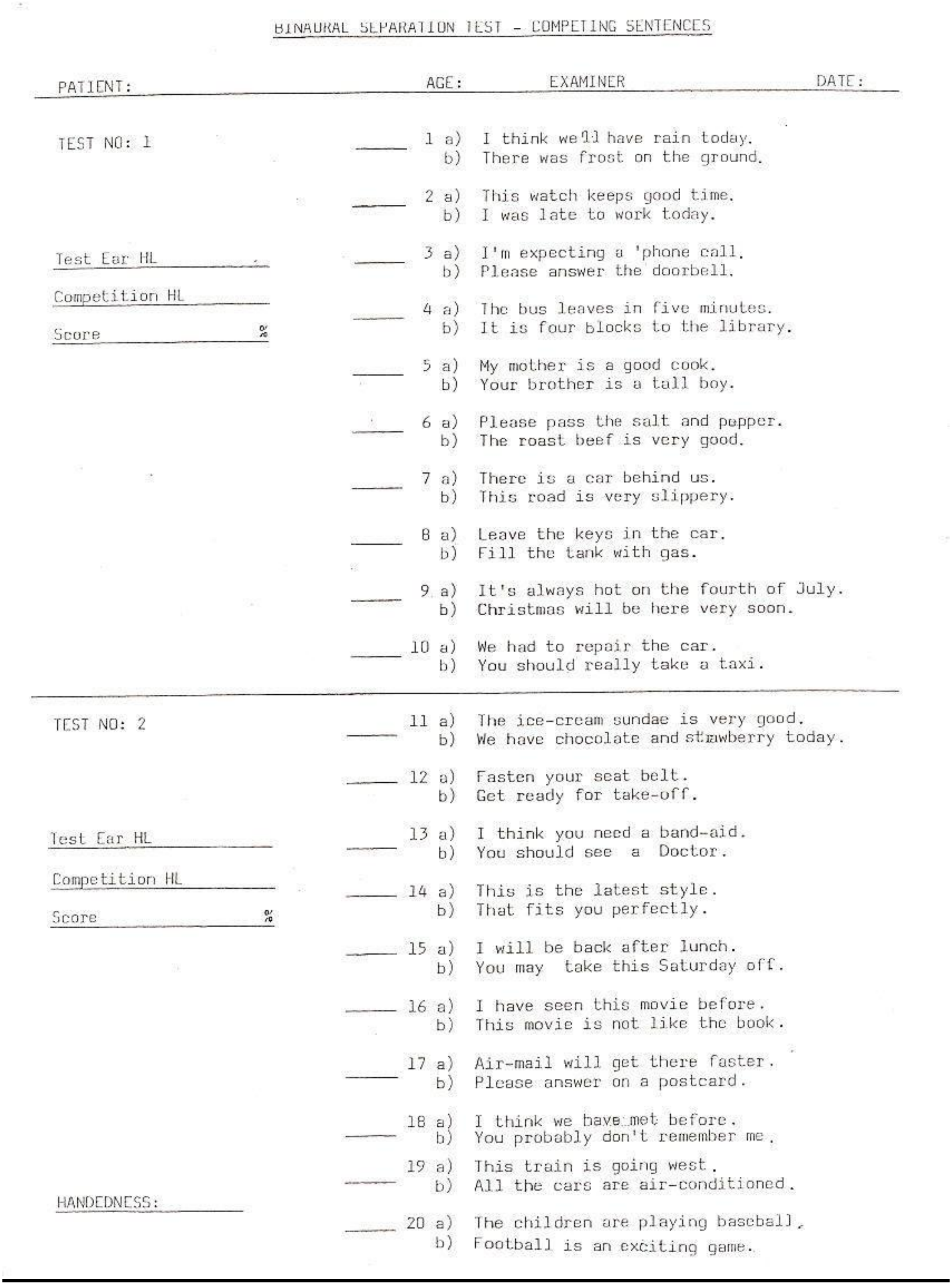
1	2	3	4
FIRST SPONDEE		SECOND SPONDEE	
☐ Sig		☐ N. Sig	

COMBINED TOTALS

	RNC	RC	LC	LNC
Ⓐ · Ⓓ or Ⓔ · Ⓗ				
Ⓗ · Ⓔ or Ⓓ Ⓐ				

Enter these figures on Page 1

Appendix D: Flinders University Auditory Processing Battery –Score Forms (2 of 4)



BINAURAL SEPARATION TEST - COMPETING SENTENCES

PATIENT: AGE: EXAMINER DATE:

TEST NO: 1

Test Ear HL ________

Competition HL ________

Score ________ %

_____ 1 a) I think we'll have rain today.
b) There was frost on the ground.

_____ 2 a) This watch keeps good time.
b) I was late to work today.

_____ 3 a) I'm expecting a 'phone call.
b) Please answer the doorbell.

_____ 4 a) The bus leaves in five minutes.
b) It is four blocks to the library.

_____ 5 a) My mother is a good cook.
b) Your brother is a tall boy.

_____ 6 a) Please pass the salt and pepper.
b) The roast beef is very good.

_____ 7 a) There is a car behind us.
b) This road is very slippery.

_____ 8 a) Leave the keys in the car.
b) Fill the tank with gas.

_____ 9 a) It's always hot on the fourth of July.
b) Christmas will be here very soon.

_____ 10 a) We had to repair the car.
b) You should really take a taxi.

TEST NO: 2

Test Ear HL ________

Competition HL ________

Score ________ %

_____ 11 a) The ice-cream sundae is very good.
b) We have chocolate and strawberry today.

_____ 12 a) Fasten your seat belt.
b) Get ready for take-off.

_____ 13 a) I think you need a band-aid.
b) You should see a Doctor.

_____ 14 a) This is the latest style.
b) That fits you perfectly.

_____ 15 a) I will be back after lunch.
b) You may take this Saturday off.

_____ 16 a) I have seen this movie before.
b) This movie is not like the book.

_____ 17 a) Air-mail will get there faster.
b) Please answer on a postcard.

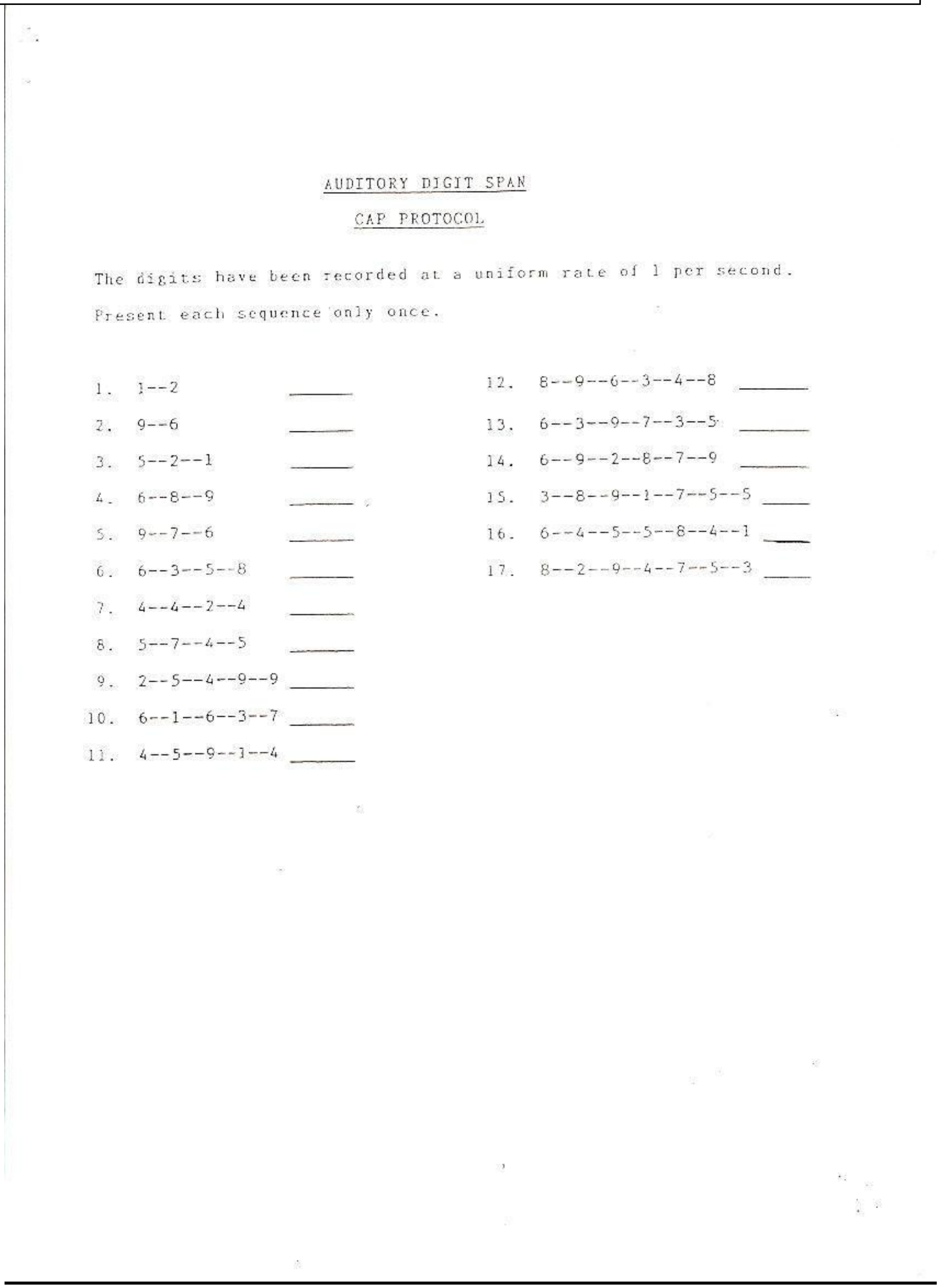
_____ 18 a) I think we have met before.
b) You probably don't remember me.

_____ 19 a) This train is going west.
b) All the cars are air-conditioned.

_____ 20 a) The children are playing baseball.
b) Football is an exciting game.

HANDEDNESS: ________

Appendix D: Flinders University Auditory Processing Battery –Score Forms (3 of 4)



AUDITORY DIGIT SPAN

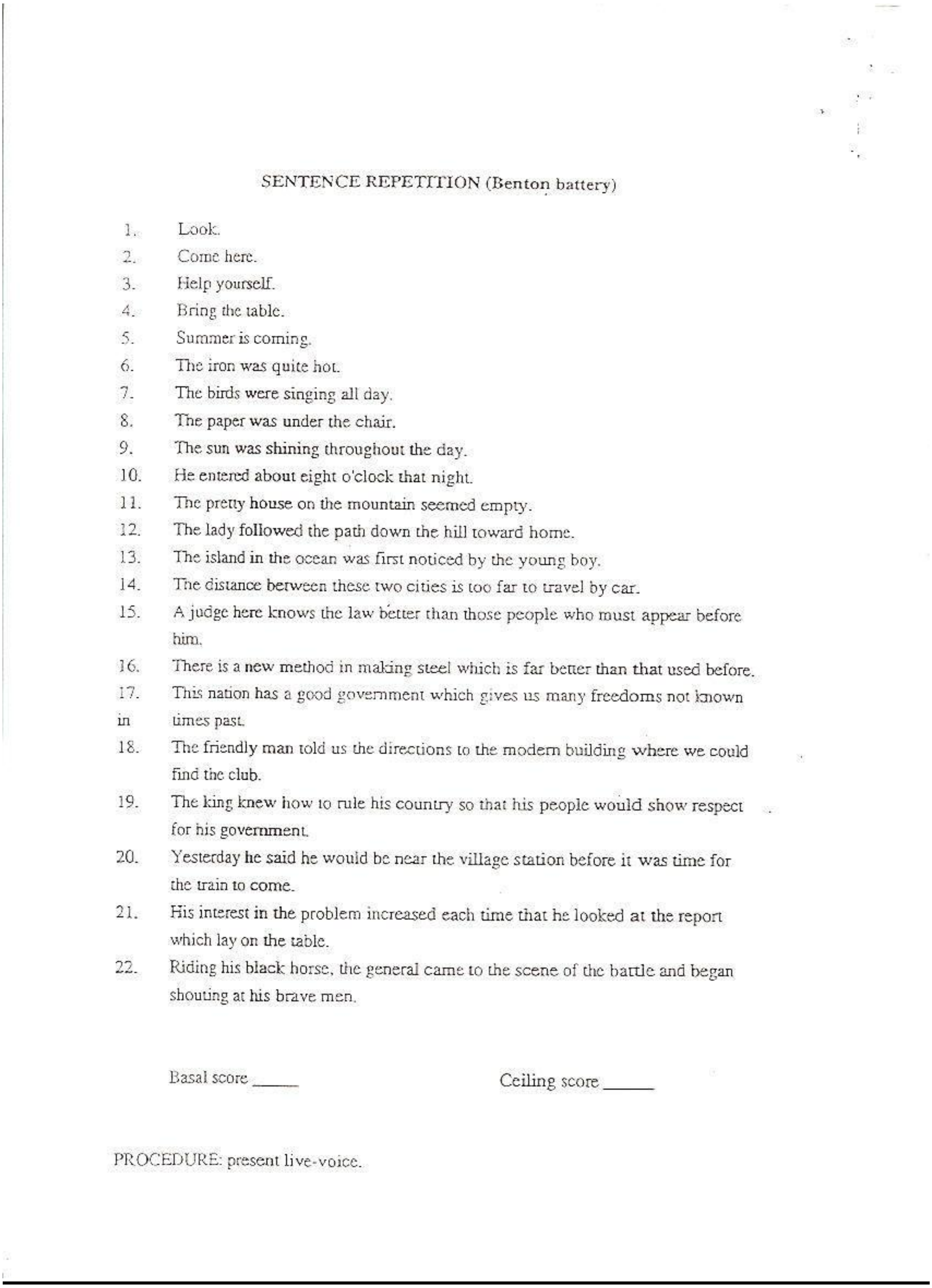
CAP PROTOCOL

The digits have been recorded at a uniform rate of 1 per second.

Present each sequence only once.

1. 1--2 ______
2. 9--6 ______
3. 5--2--1 ______
4. 6--8--9 ______
5. 9--7--6 ______
6. 6--3--5--8 ______
7. 4--4--2--4 ______
8. 5--7--4--5 ______
9. 2--5--4--9--9 ______
10. 6--1--6--3--7 ______
11. 4--5--9--1--4 ______
12. 8--9--6--3--4--8 ______
13. 6--3--9--7--3--5 ______
14. 6--9--2--8--7--9 ______
15. 3--8--9--1--7--5--5 ______
16. 6--4--5--5--8--4--1 ______
17. 8--2--9--4--7--5--3 ______

Appendix D: Flinders University Auditory Processing Battery –Score Forms (4 of 4)



SENTENCE REPETITION (Benton battery)

1. Look.
2. Come here.
3. Help yourself.
4. Bring the table.
5. Summer is coming.
6. The iron was quite hot.
7. The birds were singing all day.
8. The paper was under the chair.
9. The sun was shining throughout the day.
10. He entered about eight o'clock that night.
11. The pretty house on the mountain seemed empty.
12. The lady followed the path down the hill toward home.
13. The island in the ocean was first noticed by the young boy.
14. The distance between these two cities is too far to travel by car.
15. A judge here knows the law better than those people who must appear before him.
16. There is a new method in making steel which is far better than that used before.
17. This nation has a good government which gives us many freedoms not known
in times past.
18. The friendly man told us the directions to the modern building where we could find the club.
19. The king knew how to rule his country so that his people would show respect for his government.
20. Yesterday he said he would be near the village station before it was time for the train to come.
21. His interest in the problem increased each time that he looked at the report which lay on the table.
22. Riding his black horse, the general came to the scene of the battle and began shouting at his brave men.

Basal score _____

Ceiling score _____

PROCEDURE: present live-voice.

Appendix E: Flinders University Digit Span Normative Data

DIGIT SPAN NORMATIVE DATA

AGE	N	Mean	SD	1SD below	2SD below
7;0-7;11	44	5.2	.7	4.5	3.7
8;0-8;11	51	5.6	1.2	4.4	3.2
9;0-9;11	29	5.6	1.0	4.6	3.7
10;0-10;11	51	5.8	.8	5.0	4.2
TOTAL	175				

The normative data were established originally in 1988 to 1989 on 120 children aged 7 years to 10 years 11 months recruited from four schools in metropolitan Adelaide: Scotch College, Belair Primary, Darlington Primary and St. Theresa's Catholic School, originally 40 in each age group. The families of children in Years 2, 3 and 5 were recruited though the school newsletter and packages of information forwarded to responding parents by the school office. Paid research assistants collected the data. Subsequent funding was granted to get further normative data on the 9 year old population as the range was too large to interpolate between the 8 and the 10 year olds and the breadth of normal so wide in the younger age groups. Since then, the norms have been added to from a few research studies in which age and gender matched controls were needed for children with either APD or ADHD and the control children fulfilled the criteria for use in the normative data.

Linnett Sanchez
Associate Professor, Audiology
Flinders University

PHD/testing/digitspannormativedata.doc

Appendix F: Information Sheet and Invitation to Participate in the Research-Parents

FLINDERS UNIVERSITY
ADELAIDE • AUSTRALIA

GPO Box 2100
Adelaide 5001 Australia

Telephone:(+61 8) 8204 5942
Fax: (+61 8) 8204 5935
Email: steph.mallen@flinders.edu.au

Stephanie Mallen
Department of Speech Pathology and Audiology
School of Medicine, Faculty of Health Sciences

22 June 2004

INFORMATION SHEET

I am inviting your child to participate in a research project entitled:

"An investigation of the reading abilities of students with auditory processing disorder".

This is a research project requiring one session only. You do not have to be involved. If you do not wish to participate your child's schooling will not be affected in any way.

I am currently seeking to evaluate students ***without*** a diagnosed auditory processing disorder. Your child has been identified as having normal auditory processing abilities and as being an average reader.

This study will investigate the reading abilities of two groups of students aged between 7 and 12 years :

- with a diagnosed auditory processing disorder
- without a diagnosed auditory processing disorder

An auditory processing disorder can include difficulties with hearing differences in speech sounds, hearing against background noise, remembering information that was heard or listening for long periods. This study aims to investigate firstly, whether students with an auditory processing disorder are experiencing reading difficulties to a greater extent than students without an auditory processing disorder. Secondly this research aims to investigate whether there is any pattern to those reading difficulties. This research may provide valuable information about the nature of both auditory processing disorders and reading difficulties.

If you consent to participate you will be asked firstly, to complete a brief questionnaire containing questions about the following:

- your child’s speech and language development
- your child’s medical history
- your child’s academic history
- any help your child has received or may be currently receiving for reading or speech/language development
- your family background

The questionnaire should take about 20 minutes to complete. You do not need to respond to any question that you find too intrusive or too difficult to answer.

In order to participate in this project your child **must** have:

- no intellectual impairment,
- English as a first language
- normal hearing
- normal vision (with or without glasses)
- no neurological conditions such as autism or epilepsy

If your child is currently taking medication for Attention Deficit Hyperactivity Disorder he or she **will** be able to participate in the project and medication should be taken on the day of assessment as per usual. Similarly, if glasses are prescribed for reading they should be worn on the day of assessment.

If your child’s intellectual functioning has been evaluated by a psychologist I will request a copy of these results as the profile of abilities may provide valuable information that links to reading performance. The questionnaire and these reports will need to be returned *prior to your appointment*. You will then be contacted to arrange a convenient appointment time. At the session I will :

- review the questionnaire
- screen hearing (pure tone audiometry)
- administer the Raven’s Coloured Progressive Matrices

The Raven’s Coloured Progressive Matrices are devised to test your child’s ability to detect patterns contained in designs. The following language and reading tests will then be administered:

- Peabody Picture Vocabulary Test - III
- Clinical Evaluation of Language Fundamentals: Listening To Paragraphs subtest
- Sentence Length test
- selected subtests of the Woodcock Reading Mastery Tests- Revised
- Neale Analysis of Reading Ability – 3

These first three tests will look your child’s word knowledge and language understanding and short-term memory for language. The latter two tests look at how your child reads letters, nonsense words, real words and then paragraphs. With your consent, the reading tests will be audiotaped for later study. It is anticipated that the session will take between 75-90 minutes. The assessment can be conducted over two sessions if you wish.

There are no foreseeable risks or adverse effects associated with any of the procedures. If you or your child, as participants of this research, suffer injury, compensation may, at the discretion of Flinders University, be paid without litigation. However, compensation is not automatic and you may have to take legal action in order to receive payment.

Your involvement in this study is entirely voluntary and you may withdraw at any stage including during data collection. Should you decide to withdraw you may do so freely and without prejudice. A decision not to participate will not adversely affect your child's academic achievement or their relationship with the teacher or the school. Your decision to participate in this research *will not* affect any support that your child may currently be receiving.

All records containing personal information will remain confidential and no information that could lead to the identification of you or your child will be released. Students will be allocated a code which will appear on all data collected. Students' names will not appear on any of the test forms. The data will be securely stored at the Royal Brisbane & Women's Hospital. Individual results will be provided to you in the form of a written summary posted to your home.

The project will be conducted under the supervision of Associate Professor Linnett Sanchez and Dr. Willem van Steenbrugge within the Department of Speech Pathology and Audiology, School of Medicine at Flinders University, South Australia and Professor Barbara Dodd at the Perinatal Research Centre, Royal Brisbane & Women's Hospital.

This research has been reviewed by the Flinders Clinical Research Ethics Committee and the Queensland Department of Education and the Arts. Should you wish to discuss the study with someone not directly involved, in particular in relation to matters concerning policies or your rights as a participant, or should you wish to make a confidential complaint, you may contact Dr. Roland Simons, Senior Research Officer, Strategic Research Officer, Strategic Policy and Education Futures Division on 07-3237 0417 or the Administrative Officer- Research, Ms. Carol Hakof, at Flinders Medical Centre Ph 08-8204 4507.

If you and your child are willing to participate please complete the enclosed Consent Form and Questionnaire and return them to **Stephanie Mallen, PO Box 1133 Toowong BC, 4066 by _______/06.**

Please do not hesitate to contact me if you have any questions. I can be contacted on 0414 820 943 on Mondays, Wednesdays or Fridays. Alternatively you are welcome to contact my Queensland supervisor, Professor Barbara Dodd on 07 –3636 4401 .

STEPHANIE MALLEN	BARBARA DODD, PhD.
PhD. Student	ARC Research Professor

APPENDIX G: PARENT CONSENT TO PARTICIPATE IN RESEARCH

FLINDERS MEDICAL CENTRE
FLINDERS UNIVERSITY OF SOUTH AUSTRALIA

I, ______________________ request and give consent to
first or given names surname

______________________ 's involvement in the research project
first or given names surname

The reading abilities of students with auditory processing disorder.

I acknowledge that the nature, purpose and contemplated effects of the research project, especially

as far as they affect ______________________ have been fully explained to
first or given names surname

my satisfaction by Stephanie Mallen and my consent is given voluntarily
first or given names surname

I acknowledge that the detail(s) of the following procedure(s):

- screen of hearing

- Raven's Coloured progressive Matrices	Clinical Evaluation of Language Fundamentals: Listening to Paragraphs
- Sentence length test	Woodcock Reading Mastery Tests - Revised
- Peabody Picture Vocabulary Test	Neale Analysis of Reading Ability - 3

have been explained to me, including indications of risks; any discomfort involved; anticipation of length of time and the frequency with which the procedure(s) will be performed.

I have understood and am satisfied with the explanations that I have been given.I understand that the reading assessments will be audiotaped.

I have been provided with a written information sheet. I understand that all information collected will be kept confidential and it will not be possible to identify my child in any published reports.

I understand that ______________________ 's involvement
first or given names surname

in this research project and/or the procedure(s) may not be of any direct benefit to him/her and that I may withdraw my consent at any stage without affecting his/her rights or the responsibilities of the researchers in any respect. A decision not to participate will not adversely affect your child's academic achievement or their relationship with the teacher or the school.

I acknowledge that I have been informed that should he/she receive an injury as a result of taking part in this study, legal action may need to be taken in order to receive compensation.
I have discussed the project with my child and he/she has agreed to participate.

I declare that I am over the age of 18 years.

Signature of parent/legal ______________________ Date: ______________

Relationship to participant: ______________________

Signature of Witness: ______________________

Printed Name of Witness: ______________________

I assent to taking part in this study.

Signature of participant (child): ______________________ School: ______________

I, Stephanie Mallen have described to ______________________

the research project and the nature and effects of the procedure(s) involved. In my opinion he/she understands the explanation and has freely given his/her consent.

Signature: ______________ Date: ______________ Status: ______________

Appendix H: Parent Questionnaire

QUESTIONNAIRE

BACKGROUND INFORMATION

SCHOOL:_______________________CLASS TEACHER:_______________
Surname of Child__________________First Name__________________
D.O.B.____/_____/____AGE___ years____months YEAR LEVEL_____
Surname/s of Parent/Guardian_________________________________
First Name/s of Parent/Guardian_______________________________
Address____
____
Phone;(H)_______________(W)______________(M)_______________

DEVELOPMENTAL HISTORY

1. **Do you have any concerns about your child's speech and language development?**

   YES/NO

2. **Have you ever had any concerns about your child's speech and language development?**

   YES/NO

3. **Has your child ever been assessed by a speech pathologist?**

   YES/NO

   If so, at what age was your child first assessed? __________
   Please give diagnosis if known

____

4. **Has your child ever received therapy via a speech pathologist?**

   YES/NO

   If so, for how long? _____________________________________

What was the main focus of therapy e.g. speech, language, literacy, stuttering?

____
____

MEDICAL HISTORY

5. Has your child ever experienced an ear infection?

YES/NO

If so, approximately how many episodes?___________________

1. **Has your child ever been *treated* for an ear infection?**

   YES/NO

2. **If so, what was the treatment (please include insertion of tubes/grommets, if any)?**

   ____
   ____

3. Does your child have any known *visual* difficulties?

YES/NO

If so, please describe

____

---

8. Does your child have any medication prescribed for him/her?

YES/NO

If so, please state current medications and purpose

____

____

9. Does your child have a behavioural disorder (e.g. attention deficit disorder, conduct disorder, oppositional defiant disorder)?

YES/NO

Has your child ever been assessed for Attention Deficit Disorder?

YES/NO

10. Does your child have any other diagnosed medical/neurological conditions?

YES/NO

If so, please give details of diagnosis

____

____

EDUCATIONAL HISTORY

11. Do you have any concerns about your child's progress at school?

YES/NO

If yes, please rank your concerns from 1 (most) to 6 (least) below:

Listening ☐ Reading ☐ Spelling ☐ Writing ☐ Maths☐ Sport ☐

12. Do you have any concerns about your child's reading progress?

YES/NO

13. Does your child have any known reading difficulty? YES/NO

14. Has your child's reading been formally assessed by the school, a tutor, a speech pathologist or psychologist/ guidance officer?

YES/NO

15. Has your child ever received assistance for reading? YES/NO

16. Does your child receive any assistance with his/her reading now?

YES/NO

If so, please explain when this assistance commenced and the type of assistance (e.g. class teacher, special education teacher, tutor, speech pathologist, psychologist/guidance officer, private learning centre)

____

____
____

What are/were the main concerns about your child's reading?

____
____
____

17. Has your child's intellectual functioning been assessed by a psychologist/guidance officer?

YES/NO

If so, what were the results?

____
____
____

N.B. Please send or a copy of these results with this questionnaire or bring a copy with you to your first appointment**.**

FAMILY HISTORY

18. Is English your child's first language ?

YES/NO

19. Is there any history of reading/learning difficulties in your immediate or extended family?

YES/NO

20. State highest level of education of natural mother (please tick)
Year 10-11 ☐ Year12 ☐ Diploma/Certificate ☐ Bachelor degree ☐ Higher degree☐

21. State highest level of education of natural father (please tick)
Year 10-11 ☐ Year12 ☐ Diploma/Certificate ☐ Bachelor degree ☐ Higher degree ☐

Is there anything else you wish to mention about your child?

____
____
____

THANK YOU FOR YOUR TIME IN COMPLETING THIS QUESTIONNAIRE. PLEASE RETURN IT (TOGETHER WITH ANY RELEVANT REPORTS) TO <u>STEPHANIE MALLEN, PO BOX 1133, TOOWONG BC, 4066.</u>

IF YOUR CHILD IS ELIGIBLE FOR INCLUSION IN THE STUDY I WILL CONTACT YOU TO ARRANGE A CONVENIENT ASSESSMENT TIME AT THE SCHOOL. YOU ARE WELCOME TO ATTEND.

Appendix I: Reading Accuracy Profile (RAP)

Name:	dob: / / Date: / / Source:	
ERROR ANALYSIS	**ERROR TRANSCRIPTION**	
1. Loses Place- Visual		
2. Recast – Meaning		
3. Deletion- Word		
4. Addition - Word		
5. Letter reversal - Visual		
6. Word reversal – Visual		
7. Substitution from first letter/sound		
8. Substitution from first syllable/s		
9. Substitution from word shape		
10. Substitution from meaning		
11. Substitution –poor relationship		
12. Decoding error/ Mispronunciation		
13. Deletion – sound/syllable		
14. Addition – sound/syllable		
15. Other e.g. refusal, articulation error, naming effort		
MEANING RETAINED:	=	**SELF-CORRECTIONS**
MEANING LOST:	=	=
TOTAL ERRORS:	=	
Percentage Meaning Lost/Total Errors %	Percentage Meaning Retained/Total Errors %	
Meaning Lost less S-C %	Meaning Retained plus S-C% %	

Appendix J: Guidelines for Reading Accuracy Profile

READING ERROR GUIDE

PURPOSE

We are interested in the reading errors made by the student on the Neale Analysis of Reading Ability. Only include errors below the ceiling paragraph. Do not include the practice paragraph. Include every attempt at the word as a separate error, not just the final product. Include errors that are self-corrected.

PROCEDURE

1) Ascribe an ordinal number (1, 2, 3 etc) to each error for cross-checking.

2) Place this number on the original transcription and on the analysis sheet in the correct box. There are 15 error types plus a measure of whether meaning has been lost or retained.

3) Place each error in the correct box and write the error beside it e.g. 1. spot/stop indicating student read ‘spot’ instead of ‘stop’ (in Box 9 – substitution from word shape).

4) If the error was self-corrected place the number of the error in the self-correction box at bottom of the page.

5) EVERY error then needs to be marked as either ‘meaning retained’, ‘meaning lost’ in the bottom RHS box.

6) Errors that are self-corrected are judged as ‘meaning lost’ or ‘meaning retained’ BEFORE the self-correction.

7) Meaning is considered to be lost if the word given affects the meaning of the sentence. Errors such as ‘a’ for ‘the’ will sometimes affect the meaning of the sentence and other times not – you will need to decide if meaning has been affected. Read the sentence to yourself with the error intact and determine whether it means the same as the target sentence. For example, changes of tense DO affect meaning e.g. ‘He had a friend’ has a different meaning to ‘He has a friend’. In contrast, ‘the back of sheeps’ holds the same meaning as ‘the backs of sheep’ and ‘a long time ago’ means the same as ‘long ago’ as does ‘each others’ and ‘each other’. Do not try to judge whether *the student’s* understanding was affected or the severity of the loss of meaning; use your own judgement as to whether the meaning is the same as the intended text .

8) Total all errors that retained meaning, lost meaning or were self-corrected when you have finished. Calculate percentages of errors which resulted in lost meaning, with and without self-corrections of lost meaning *only*.

ERROR TYPES

N.B. For each student errors will commonly cluster around particular types, leaving other boxes blank – this is to be expected. An explanation of each error type is outlined below;

1. **Loses place- visual**; This will be identified by 'lost place' written in side column. If whole phrases or lines are omitted then meaning is lost. If the child finds his or her place again then meaning is retained.

2. **Recast – meaning**; This will be identified by an arrow from where the recast began back to where it finished indicating that the child re-read a section of text to regain meaning. If the recast is correct then meaning has been retained. If not, meaning may have been lost. If an error occurred prior to the recast it is categorized separately (usually meaning lost) and if it is then corrected in the recast it is considered a self-correction. For example if 'with which' is read as 'which which' the error with/which is placed in Error Type 9 and meaning is lost. A recast which results in 'with which' is placed in Error Type 2 and meaning is retained. The original error has now been self-corrected and is placed in the self-correction box. Do NOT include a recast of a word corrected by the examiner, only spontaneous recasts. A recast is still considered an error; the error is NOT having moved to the next word.

3. **Deletion –whole word;** A diagonal line will be placed through the word. Whole word has been deleted.

4. **Addition –whole word;** An upward arrow will indicate a whole word has been added. The word will be placed above this.

5. **Letter reversal;** This occurs when a letter within the word has been reversed resulting in an error e.g. bad/dad, wet/met.

6. **Word reversal;** This occurs only for word or part-word reversals (2 or more letters reversed) e.g. was/saw, on/no – oh/no and of/for are acceptable word reversals.

7. **Substitution from first letter/sound;** The first letter, digraph, sound or consonant blend matches the target e.g. it/in, date/dead, his/her, black/blue. Sometimes there are matching letters later in the word, but the word shape of the remainder does not match the target e.g. iron/ignoring. Error is a real word. It will be assumed that meaning may have influenced the error as well.

8. **Substitution from first syllable/s;** The first syllable/s match the target but not the remainder of the word e.g. offence/offside, searching/searched, telephone/television. This error type must at least contain the first vowel sound e.g. track/ traffic, joint/pointed. Error is a real word. It will be assumed that meaning may have influenced the error as well.

9. **Substitution/word shape influence;** The substituted word/s will be written below the target word. You will need to decide whether you think the shape of the whole word influenced the error e.g. purpose/porpoise, safely/safety crash/crush, were/where compared to the first syllable/s only. Error is a real word. Exclude

whole word or letter reversal errors (see 5 & 6). Place error here when there is a visual similarity even if meaning may have had some influence as well.

10. **Substitution/meaning influence**; The substituted word makes sense but does not look similar to the target e.g. a/the, river/creek. Error is a real word. There needs to be a justifiable reason why student was influenced by meaning more than visual aspects of the word as in errors 7,8,9. You can also be guided by the pattern of the particular student you are analysing.

11. **Substitution/poor relationship**; This occurs when there is no apparent relationship between the error and the target word e.g. it/this, her/was and the word does not make sense in the sentence thus far. Sometimes, some letters in the error are contained in the target, often out of order e.g. face/traffic, hopped/pointed. Error is a real word.

12. **Mispronunciation/decoding error;** This occurs when the student decodes the word and pronounces it incorrectly e.g. instayntly/instantly. Place errors here even if mispronunciation of target *after sounding* ends up sounding like another real word. Part-word decoding errors are placed here. Usually meaning is considered to be lost, except for mispronunciation of people's names. Accurate sounding does not classify as an error, but frequent reliance on sounding aloud may be noted.

13. **Deletion of part-word or morpheme;** This occurs when part of the word is missing (morphemes or part of a compound word) e.g. smile/smiles, burrow/burrowing, cray/crayfish or words are contracted e.g. can't/cannot, I'd/I would, bikes/bicycles. The root word must be the same in the target and the error e.g. a/an.

14. **Addition of part-word or morpheme**; This is the opposite of the above e.g. smiles/smile, burrowing/burrow, lunchtime/lunch, cannot/can't. The root word must be the same in the target word and the error word e.g. into/to.

15. **Other;** All other errors can be placed here e.g. refusal to read a word after looking at it – a refusal will be marked with 'Ref'. Common mispronunciations such as 'exscape' for 'escape' or 'aksed' for 'asked' can be placed here, with meaning retained. Note any obvious letter or word naming effort in this box. If the error is unintelligible place the number of the error here also.

Appendix K: Ethical Approval: Department of Education and the Arts, Queensland

Queensland Government
Department of Education and the Arts 2 June 2005

Ms Stephanie Mallen

PO Box 1133
TOOWONG QLD 4066

Dear Ms Mallen

Thank you for your application seeking approval to conduct research titled *"The reading abilities* of *students with auditory processing disorder"* in Queensland State Schools. I wish to advise that your application has been approved subject to your confirmation of participating schools.

This approval means that you can approach principals of schools and invite them to participate in your research project. As detailed in the research guidelines:

. You need to obtain consent from the relevant principals before your research project can commence.

. Principals have the right to decline participation if they consider that the research will cause undue disruption to educational programs in their schools.

. Principals have the right to monitor any research activities conducted in their facilities and can withdraw their support at any time.

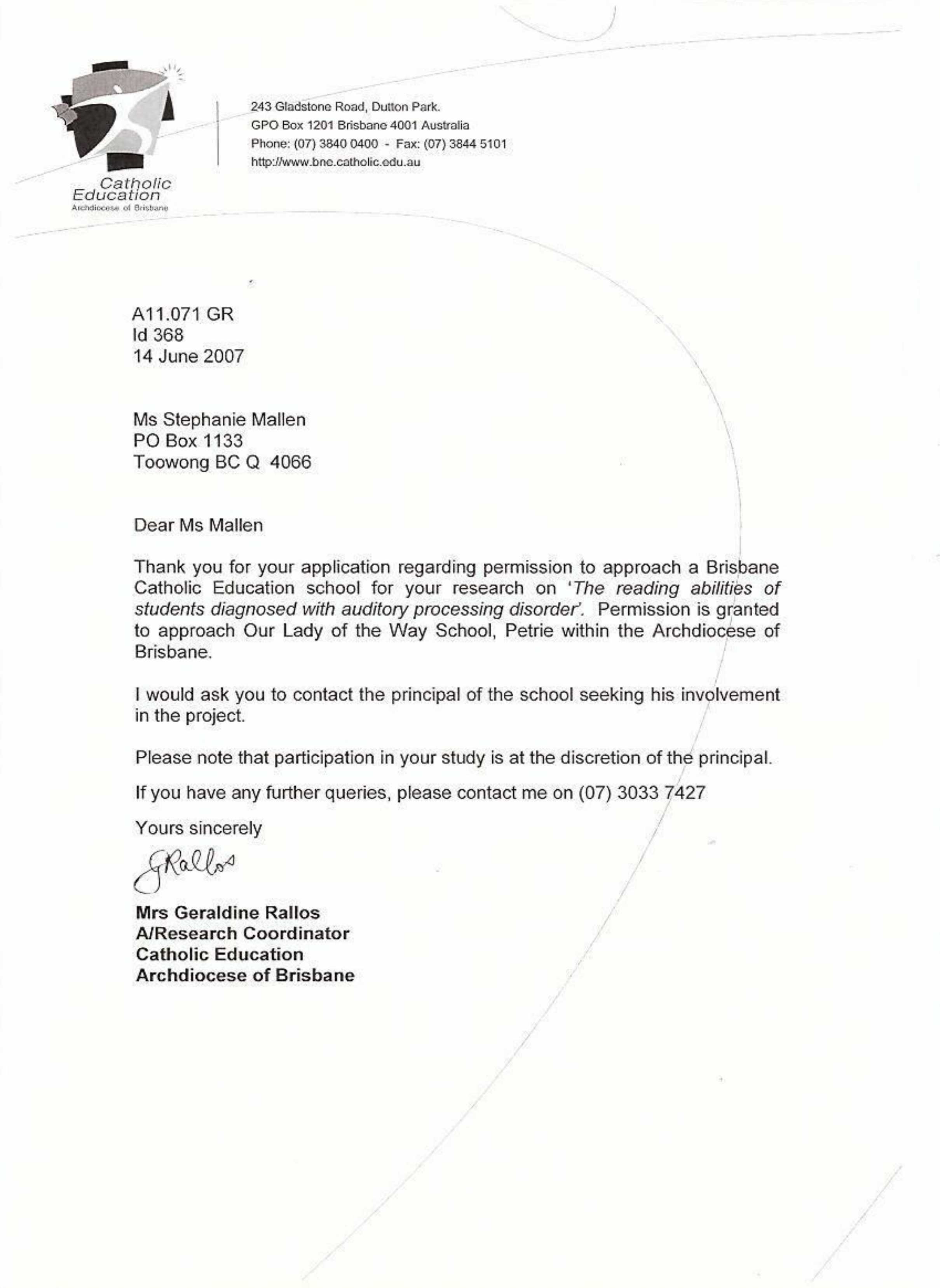
At the conclusion of your study, you are required to provide the Department of Education and the Arts with a summary of your research results and any published paper resulting from this study. A summary of your research findings should also be forwarded to participating principals.

Please note that this letter constitutes approval to invite principals to participate in the research project as outlined in your research application. This approval does not constitute support for the general and commercial use of an intervention or curriculum program, software program, or other enterprise that you may be evaluating as part of your research.

Should you require further information on the research application process please do not hesitate to contact Dr Roland Simons, Senior Research Officer, Strategic Policy and Education Futures Division on (07) 3237 0417. Please quote the file number 550/27/339 in future correspondence.

Yours sincerely
U/V~~
Carol Markie-Dadds
A/Assistant Director Strategic Policy and Education Futures Education Futures Level 21 Education House
Strategic Policy and Education Futures Division 30 Mary Street Brisbane 4000
PO Box 15°33 City East Trim ref: 05/50866 Queensland 4002 Australia Telephone +61 7 3405 5738 Facsimile +61 7 32371175
Website www.education.qld.gov.au ABN 76 337 613 647

Appendix L: Ethical Approval: Catholic Education, Archdiocese of Brisbane



Catholic Education
Archdiocese of Brisbane

243 Gladstone Road, Dutton Park.
GPO Box 1201 Brisbane 4001 Australia
Phone: (07) 3840 0400 - Fax: (07) 3844 5101
http://www.bne.catholic.edu.au

A11.071 GR
Id 368
14 June 2007

Ms Stephanie Mallen
PO Box 1133
Toowong BC Q 4066

Dear Ms Mallen

Thank you for your application regarding permission to approach a Brisbane Catholic Education school for your research on '*The reading abilities of students diagnosed with auditory processing disorder'*. Permission is granted to approach Our Lady of the Way School, Petrie within the Archdiocese of Brisbane.

I would ask you to contact the principal of the school seeking his involvement in the project.

Please note that participation in your study is at the discretion of the principal.

If you have any further queries, please contact me on (07) 3033 7427

Yours sincerely

GRallos

Mrs Geraldine Rallos
A/Research Coordinator
Catholic Education
Archdiocese of Brisbane

LIST OF PARTICIPATING SCHOOLS-QUEENSLAND

State Schools
Albany Creek State School
Boondall State School
Glasshouse Mountains State School
Kedron State School
Mountain Creek State School
Sandgate State School
Shorncliffe State School
Wavell Heights State School
Wilston State School
Yandina State School

Catholic Education Schools
Our Lady of the Way Catholic School
St. Dympna's Catholic School

Phd/recruiting/listofparticipatingschools.doc

FLINDERS UNIVERSITY
ADELAIDE • AUSTRALIA

Department of Speech Pathology and Audiology
GPO Box 2100
Adelaide 5001 Australia

Telephone: (+61 8) 8204 5942
Fax: (+61 8) 8204 5935
Email:

28 August 2006

Dear Principal

I am writing to invite your school to participate in a PhD research project entitled:

"The Reading Abilities of Students with Auditory Processing Disorder (APD)"

My name is Stephanie Mallen and I am studying in Queensland as an external student of Flinders University, South Australia. Fortunately, I have completed the assessment of the reading abilities of students who have an auditory processing disorder. I am now seeking students who do *not* have APD and who have average reading abilities as a comparison group. I am seeking 7 students in the range of 7 years to 12 years of age. Only one session is required with each student.

If your school participates in the study, I would be asking interested teachers to identify students (of a specified age & gender) in their class who:

- demonstrate what the teacher considers to be average reading for their age
- have no history of learning support
- have no known history of speech or language support
- have no known history of hearing loss or recurrent ear infections

I am happy to assist teachers or your learning support teacher with the identification of suitable students. Once a student has been identified, the parents/guardians of that student will be invited to participate in the research. Those who complete the consent form will then be asked to complete a questionnaire regarding the student's medical, developmental, educational and family history to ascertain that the selected students have;

- no intellectual impairment
- normal or corrected vision
- English as a first language
- no neurological conditions

If all of the above inclusion criteria have been met, the family will then be contacted to arrange a convenient session time at the school. I would then seek your assistance in the provision of a suitable quiet room for about 90 mins for the assessment of each child.

I will administer the assessment sessions. I am a practising speech pathologist with 14 years paediatric experience. At the session the student will be asked to perform:

- a screening test of hearing ability
- an evaluation of short-term memory for language (Sentence Recall)
- an evaluation of non-verbal reasoning (Raven's Coloured Progressive Matrices)
- an evaluation of vocabulary understanding (Peabody Picture Vocabulary Test-3)
- an evaluation of listening comprehension (Clinical Evaluation of Language Fundamentals; Listening to Paragraphs subtest)
- an evaluation of reading ability (Woodcock Reading Mastery tests and Neale Analysis of Reading Ability)

The anticipated session time is approximately 75-90 minutes. However, the assessment can be performed over two sessions if the parents wish. All participating families will receive a short written summary of the student's results.

This research has been approved by the Queensland Department for Education and the Arts and Catholic Education, Brisbane. A copy of the approval letter is attached. The aim of this research is to determine whether auditory processing deficits have a significant impact on reading development. Secondary aims are to establish whether the severity of those deficits is correlated to the severity of reading difficulties and to explore differences between the reading errors (reading accuracy) and reading comprehension of average readers compared to readers with auditory processing deficits. At the completion of the project, all participating schools and the Department for Education and the Arts will receive a report of the findings. The Department for Education and the Arts will also be notified of your involvement.

All personal information will remain confidential and will be securely stored. Students will be allocated a code which will appear on all data collected. Students' names will not appear on any of the test forms.

If you are interested in your school participating, please complete the attached 'Expression of Interest' form and return in the enclosed envelope **by ____/06**. The 'Expression of Interest' does not bind your school to involvement in the project. I will contact you shortly after this date to answer any questions that you may have and to establish if you are willing to participate. I will also explain how to proceed with identification of students within your school.

If you have any further queries relating to this research I can be contacted on 0414- 820943 on Mondays, Wednesdays and Fridays. Alternatively you are welcome to contact my Queensland supervisor, Professor Barbara Dodd, Australian Research Council Research Professor on 07-36364401. Thank you for considering this invitation.

STEPHANIE MALLEN
Speech Pathologist
B.App. Sc. (Speech Pathology), CPSP, MSPAA

Appendix O: Principal Expression of Interest

October 2, 2006

Expression of Interest

Research title:

The Reading Abilities of Students with Auditory Processing Disorder

I wish to express interest in the participation of (name of school)____________________________________ in the above research project.

I can be contacted on (phone number)
______________________________ at the following times
____
____
______ and understand that I will be able to ask further questions at this time.

P I understand that this expression of interest does not bind me or the above school to participation in the research project.

Principal’s name: _________________________________

Principal’s signature:_______________________________

Date:_________________

PLEASE FORWARD THIS FORM IN THE ENCLOSED ENVELOPE TO STEPHANIE MALLEN, PO BOX 1133, TOOWONG BC, 4066.

DO NOT FORWARD THE CONSENT FORM ON THE FOLLOWING PAGE UNTIL AFTER YOU HAVE BEEN CONTACTED BY PHONE. THANK YOU.

Appendix P: Principal Consent Form

October 2, 2005

Principal Consent Form

The reading abilities of students with auditory processing disorder

This research project, as outlined in the Information Sheet, is seeking to obtain data on the normal language and reading abilities of 30 students aged between 7 years and 12 years 11 months. Following class teacher identification of students with no history of auditory impairment, language intervention or literacy support, it is anticipated that between 2 and 13 students from your school would be invited to participate. Once consent is received the family/caregiver would be asked to complete a brief background history questionnaire to ensure inclusion criteria are met. The student's hearing will be screened prior to administration of language and reading assessments. It is anticipated that the sessions will be held during class time and will be of approximately 75-90 minutes duration.

☐ No, I do not give permission for the assessments to be conducted in the school.

☐ Yes, I give permission for the assessments to be conducted in the school.

☐ I understand that all information collected will be kept confidential and it will not be possible to identify the school in any published reports.

Principal: (print) ___________________________

Signature: ___________________________ Date: ___________

Once you have forwarded the Expression of Interest you will be contacted by phone. Do not send this consent form until after this contact.

Please return to: Stephanie Mallen, PO Box 1133, Toowong BC, QLD 4066

Appendix Q: Cover Letter to Class Teacher

Dear Class Teacher

Thank you for agreeing to consider your participation in the PhD research project entitled;

‘The reading abilities of students with auditory processing disorder’

Students *with* an auditory processing disorder have already been evaluated in South Australia. I am now seeking to match the reading age of these students with average readers. This will enable a thorough evaluation of the differences in reading error types and comprehension abilities between average readers and readers with an auditory processing disorder.

In your school, I am seeking *any of* the following students;

Male 7 years 5 months
2 x Males 7 years 6 months
Male 7 years 8 months
2x Female 7 years 11 months
Female 8 years 5 months
Male 8 years 1 month
2 x Male 9 years 4 months
Male 10 years 1 month
Male 10 years 7 months
Female 10 years 11 months

Ideally the student’s chronological age and reading age should match, but a slight variation is acceptable for inclusion in the study. If the student’s reading has been recently formally assessed as average this would be beneficial to ensure the student will be able to be included in the study. **Please refer to Literacy and Numeracy assessment results if possible to ensure that students are not ABOVE average readers.**

Please note that all students must have;

- no history of learning support
- no known history of speech or language support
- no known history of hearing loss or recurrent ear infections

Once you have identified prospective students, please do the following two steps;
1. Give the information letter, consent form and questionnaire to the parents/guardian. The questionnaire covers information about the child’s medical, developmental, educational and family history. It is necessary to determine from the questionnaire that the student has;

- no intellectual impairment
- normal or corrected vision
- English as a first language
- no neurological conditions

Once these inclusion criteria have been met and the parents and the child have consented to participate I will contact the family to make a suitable appointment time to assess the student at your school.

2. **Please complete the attached class teacher consent form and identification forms and return to me at PO Box 1133, Toowong BC, QLD 4066.**

At the session the student will be asked to perform;
- a screening test of hearing ability
- an evaluation of short-term memory for language (Sentence Recall)
- an evaluation of non-verbal reasoning (Raven's Coloured Progressive Matrices)
- an evaluation of vocabulary understanding (Peabody Picture Vocabulary Test-3)
- an evaluation of listening comprehension (Clinical Evaluation of Language Fundamentals; Listening to Paragraphs subtest)
- an evaluation of reading ability (Woodcock Reading Mastery tests and Neale Analysis of Reading Ability)

The anticipated session time is approximately 75-90 minutes. However, the assessment can be performed over two sessions if the parents wish. All participating families will receive a short written summary of the student's results.

This research has been approved by the Queensland Department for Education and the Arts, Catholic Education, Brisbane and Flinders University. All personal information will remain confidential and will be securely stored at the Royal Brisbane & Women's Hospital. Students will be allocated a code which will appear on all data collected. Students' names will not appear on any of the test forms.

If you are willing to participate and are able to identify students who meet the above criteria please complete the attached consent form and identification forms and return to ;

Stephanie Mallen, PO Box 1133, Toowong BC, QLD 4066

If you have any queries regarding this project I can be contacted on 0414 –820 943 on Mondays, Wednesdays and Fridays.

STEPHANIE MALLEN
Speech Pathologist
B.App. Sc (Speech Pathology), CPSP, MSPAA

Appendix R: Class Teacher Consent Form

Class Teacher Consent form

The reading abilities of students with auditory processing disorder

☐ **No, I do not give permission for the assessment to be conducted with ______________________________, a student in my class.**

--

☐ **Yes, I give permission for the assessment to be conducted with ____, a student in my class.**

☐ I understand that all information collected will be kept confidential and it will not be possible to identify the student or the school in any published reports.

Class teacher: (print) _________________________

Signature: __________________________Date _____

Please Return To:
Stephanie Mallen, PO Box 1133, Toowong BC 4066

Appendix S: Student Identification Sheet

IDENTIFICATION SHEET

Name of School:____

Class Teacher Name:_______________________________________
Year Level:___________________

Student’s name
__________________________________D.O.B._______/____/____

Parent/Guardian Name/s:
____

Home address:____

Parent/Guardian Phone number:
(H)_____________________(W)____________________________

(Mobile – mother)__________________________
(Mobile-father)_______________________________

Please detail your knowledge of the child’s reading abilities including any formal assessment results (please give name of assessment, date performed and result)

____
____
____
____
____
____
____
____
____
____
____

Do you have any preferred times for the assessment to take place?
____
____

Please Return To;
Stephanie Mallen, PO Box 1133, Toowong BC, 4066

APPENDIX T: Reading Accuracy Profile (RAP) – APD group example

Name: APD group	dob: (age 8;11) Date: / / Source:NARA-3	
ERROR ANALYSIS	ERROR TRANSCRIPTION	
1. Loses Place- Visual		
2. Recast – Meaning	2. of	
3. Deletion- Word		
4. Addition - Word		
5. Letter reversal - Visual		
6. Word reversal – Visual		
7. Substitution from first letter/sound	10.the/that	
8. Substitution from first syllable/s		
9. Substitution from word shape	1. terrific/traffic 4. listen/lesson 5. steered/sheltered 13. place/palace	
10. Substitution from meaning	3. the/a 6. the/an 11.the/a	
11. Substitution – poor relationship		
12. Decoding error/ Mispronunciation	7. /ʃɛlə//shoulder 9. /eIl//Ali 12. /Imædʒəmənt//amazement	
13. Deletion – sound/syllable		
14. Addition – sound/syllable	8.jewelleries/jewels	
15. Other e.g. refusal, articulation error		
MEANING RETAINED:	9 =1	SELF-CORRECTIONS
MEANING LOST:	1,2,3,4,5,6,7,8,10,11,12,13 =12	= 0
TOTAL ERRORS:	**=13**	
Percentage Meaning Lost/Total Errors	92%	Percentage Meaning Retained/Total Errors 8%
Meaning Lost less Self-Corrections	%	Meaning Retained Plus Self-Corrections %

APPENDIX U: Reading Accuracy Profile (RAP) – Average group example

Name: Average group	dob: (age 7;8) Date: / / Source:	
ERROR ANALYSIS	ERROR TRANSCRIPTION	
1. Loses Place- Visual		
2. Recast – Meaning	6./Instæntli:/ he was thrown into/instantly he was thrown into 12. the explored/he explored 16. a long/long ago	
3. Deletion- Word		
4. Addition - Word	15. a	
5. Letter reversal - Visual		
6. Word reversal – Visual		
7. Substitution from first letter/sound		
8. Substitution from first syllable/s		
9. Substitution from word shape	1. she/the 3. talking/taking 9. dessert/desert 11. the/he 14. place/palace	
10. Substitution from meaning		
11. Substitution –poor relationship		
12. Decoding error/ Mispronunciation	4. /Instænt//instantly 5. /Instæntli://instantly 7. /dʒu://jewels 8. /u:lu://Ali 10. /ImeIdʒ/ imagined	
13. Deletion – sound/syllable		
14. Addition – sound/syllable	2. we're/we	
15. Other e.g. refusal, articulation error	13. /ɛkskeIp//escape	
MEANING RETAINED:	2,6,8,13,15,16 =6	SELF-CORRECTIONS 2,14
MEANING LOST:	1,3,4,5,7,9,10,11,12,14 =10	1,5,7,10,11 =7
TOTAL ERRORS:	**= 16**	
Percentage Meaning Lost/Total Errors	63 %	Percentage Meaning Retained/Total Errors 37%
Meaning Lost less Self-Corrections	31 %	Meaning Retained Plus Self-Corrections 69%

Erroranalysis4.doc