# Intervention for Children with Auditory Processing Disorder (APD):

# The Effectiveness of Bottom-Up and Top-Down Interventions

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28th November, 2014

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## DECLARATION AND ETHICS STATEMENT

I certify that this thesis does not incorporate without acknowledgement 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 or written by another person except where due reference is made in the text.

The research proposal for this study was approved by the Flinders University Clinical Research Ethics Committee (approval number 426.10). This research was conducted in accordance with the National Health and Medical Research Committee’s guidelines on human experimentation. Participant confidentiality was assured.

Emilie Lam

28/11/2014

## ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my principal supervisor, Dr. Willem van Steenbrugge, for his support, guidance, hard work and commitment to see me through the candidature. I am also deeply indebted to my other supervisors, Dr. Christopher Lind and Dr. Sarosh Kapadia, for their mentorship, encouragement, and the many enjoyable, thought provoking meetings that we had. I would also like to express my heartfelt gratitude to Can:Do 4Kids for their generosity in providing the scholarship. I am also deeply obliged to Associate Professor Genevieve McArthur, Professor Dorothy Bishop and Professor Dave Moore who had so generously allowed the use of their intervention programs for this project. My deepest thank you to Dr. Bartek Rajkowski who so generously gave us licences to the ReadingSounds 1 Pro free of charge and Rob Seiler from ELR Software Pty Ltd, for giving up his time to help me with the implementation of the SoundsPod. I would also like to express my sincere appreciation to David May and Dr. Judith Boswell from Adelaide Hearing Consultants for their passion in research and their great effort in helping me with recruitment; Claire Cotton, Liz Cohen and Tanya Cantwell from Can:Do 4Kids for their support and input in the early stage of the study; Associate Professor Linnett Sanchez and Associate Professor David Turner for their mentorship, support, and friendship; Dr. Wayne Wilson and Dr. Wendy Arnott for their interest in this research; Dr. Robert Muller for his help in professional editing; and the parents and children who participated in the study, it was truly a great joy and privilege to get to know them. I would like to especially thank my parents, Andrew and Flora Lam. Their love and support saw me through the candidature. Very importantly, I would like to thank my dearest husband, Subuwanto Widjaja, for his unwavering belief in me, whose love and sacrifices had made this possible; and for my two adorable boys: Elliot and Caleb (both born during the candidature, who had been such good boys while mammy was trying to finish her “homework”. Lastly, above all, my heartfelt gratitude to God, my Heavenly Father, for His love and provision every step of the way and the many miracles and answered prayers. Indeed, His grace was sufficient for me, for His power was made perfect in my weakness (adapted from 2 Corinthians 12:9).

# DEDICATION

For Subu, Elliot and Caleb

## LIST OF ABBERVIATIONS

| | |
|---|---|
| **A** | Vargha-Delaney A |
| **ADD** | Attention Deficit Disorder |
| **ADHD** | Attention Deficit Hyperactivity Disorder |
| **AIT** | Auditory Integration Training |
| **ALNLRAC** | Assessment of Lexical and Non-Lexical Reading Abilities in Children |
| **ALNLRAC-IW-RS** | Irregular Word Reading Raw Score of the Assessment of Lexical and Non-Lexical Abilities in Children |
| **ALNLRAC-IW-ZS** | Irregular Word Reading *z*-Score of the Assessment of Lexical and Non-Lexical Abilities in Children |
| **ALNLRAC-NW-RS** | Non-Word Reading Raw Score of the Assessment of Lexical and Non-Lexical Abilities in Children |
| **ALNLRAC-NW-ZS** | Non-Word Reading *z*-Score of the Assessment of Lexical and Non-Lexical Abilities in Children |
| **ALNLRAC-RW-RS** | Regular Word Reading Raw Score of the Assessment of Lexical and Non-Lexical Abilities in Children |
| **ALNLRAC-RW-ZS** | Regular Word Reading *z*-Score of the Assessment of Lexical and Non-Lexical Abilities in Children |
| **AP** | Auditory Processing |
| **APD** | Auditory Processing Disorder |

| | |
|---|---|
| **Ax** | Assessment |
| **BM0** | Backward Masking with a Zero-Millisecond Gap |
| **BM50** | Backward Masking with a 50-Millisecond Gap |
| **CELF-4** | Clinical Evaluation of Language Fundamentals (4th Ed) |
| **CI** | Confidence Interval |
| **CON** | Control Group (STUDY 2) |
| **CTOPP** | Comprehensive Test of Phonological Processing |
| **CTOPP-PA-CR** | Phonological Awareness Composite Raw Score of the Comprehensive Test of Phonological Processing |
| **CTOPP-PA-CS** | Phonological Awareness Composite Standard Score of the Comprehensive Test of Phonological Processing |
| **CTOPP-PM-CR** | Phonological Memory Composite Raw Score of the Comprehensive Test of Phonological Processing |
| **CTOPP-PM-CS** | Phonological Memory Composite Standard Score of the Comprehensive Test of Phonological Processing |
| **CTOPP-RN-CR** | Rapid Naming Composite Raw Score of the Comprehensive Test of Phonological Processing |
| **CTOPP-RN-CS** | Rapid Naming Composite Standard Score of the Comprehensive Test of Phonological Processing |
| **CCVC** | Consonant-Consonant-Vowel- Consonant |

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|---|---|
| **CVC** | Consonant-Vowel-Consonant |
| **CVD** | Consonant Vowel Discrimination |
| **CVCC** | Consonant-Vowel-Consonant-Consonant |
| **DDT** | Dichotic Digits Test |
| **DRC** | Dual Route Cascade |
| **ERP** | Event Related Potential |
| **FD** | Frequency Discrimination |
| **FD-DIFF group** | Frequency Discrimination Difficulty Group (STUDY 1) |
| **FD-DINO-TS** | Dinosaur Task Threshold Score |
| **FD-SOUND-TS** | SoundsPod Threshold Score |
| **FD-WNL group** | Frequency Discrimination Within-Normal-Limits Group (STUDY 1) |
| **FD-PP group** | Frequency Discrimination Intervention and Phonological Processing Intervention Group (STUDY 2) |
| **FM** | Frequency Modulated |
| **FR** | Frequency Resolution |
| **ISI** | Inter-Stimuli Interval |
| **MCAR** | Missing Completely At Random |
| **MMF** | Mismatch Field |
| **MMN** | Mismatch Negativity |

| | |
|---|---|
| **PEST** | Parameter Estimation by Sequence Testing |
| **PP** | Phonological Processing |
| **PP group** | Phonological Processing Intervention Group (STUDY 2) |
| **PP-I-LS** | Phonological Processing Intervention-Specific Literacy Score |
| **PPVT-4** | Peabody Picture Vocabulary Test (4th Ed) |
| **PPVT-RS** | Peabody Picture Vocabulary Test Raw Score |
| **PPVT-SS** | Peabody Picture Vocabulary Test Standard Score |
| **RAP** | Rapid Auditory Processing |
| **RAN** | Rapid Automatic Naming |
| **RCPM** | Raven's Coloured Progressive Matrices |
| **SAT** | Simon Arrow Task |
| **SAT-CONT-ER** | Error Rate of the Control Condition of the Simon Arrow Task |
| **SAT-CONT-RT** | Reaction Time of the Control Condition of the Simon Arrow Task |
| **SAT-REV-ER** | Error Rate of the Reverse Condition of the Simon Arrow Task |
| **SAT-REV-RT** | Reaction Time of the Reverse Condition of the Simon Arrow Task |
| **SAT-CONGR-ER** | Error Rate of the Conflict Congruent Condition of the Simon Arrow Task |
| **SAT-CONGR-RT** | Reaction Time of the Conflict Congruent Condition of the Simon Arrow Task |

| | |
|---|---|
| **SAT-INCONGR-ER** | Error Rate of the Conflict Incongruent Condition of the Simon Arrow Task |
| **SAT-INCONGR-RT** | Reaction Time of the Conflict Incongruent Condition of the Simon Arrow Task |
| **SCORE-RS** | !Score Subtest Raw Score of the Test of Everyday Attention in Children |
| **SD** | Standard Deviation |
| **SM** | Simultaneous Masking with Target Tone Presented in Continuous Noise |
| **SMN** | Simultaneous Masking with Spectral Notch |
| **TEA-Ch** | Test of Everyday Attention for Children |
| **TR** | Temporal Resolution |
| **TROG** | Test of Reception of Grammar |
| **TROG-RS** | Test of Reception of Grammar Raw Score |
| **TROG-SS** | Test of Reception of Grammar Standard Score |
| **TOJ** | Temporal Order Judgement |
| **VD intervention** | Visual Discrimination Intervention |
| **VD-PP group** | Visual Discrimination Intervention and Phonological Processing Intervention Group (STUDY 2) |

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## ABSTRACT

The current recommendation for interventions for Auditory Processing Disorder (APD) is that they should involve both 'bottom-up' interventions that target specific auditory processing (AP) deficits and 'top-down' interventions targeting other cognitive abilities (e.g., language and reading) that might be impeded (ASHA, 2005; BSA, 2011b; Chermak, 1999; Chermak, & Musiek, 2007). To date, empirical research in this area is limited. The current thesis sought to investigate this recommendation empirically through two studies concerning a prominent AP ability, namely frequency discrimination (FD).

STUDY 1 aimed to investigate whether children with APD who also demonstrated FD difficulty would have poorer reading, language, auditory-sustained attention, and executive control than children with APD who had age-appropriate FD. Sixteen children with APD (aged 7;5 to 10;6), eight with FD difficulty (FD-DIFF group), and eight with age-appropriate FD (FD-WNL group) were tested for word reading, phonological processing (PP) (which included phonological awareness, phonological memory and rapid naming), language, auditory-sustained attention, and executive control. The FD-DIFF group showed significantly poorer non-word reading, regular word reading, and phonological awareness than the group with age appropriate FD. However, there were no group differences regarding irregular word reading, phonological memory, rapid naming, receptive language, auditory-sustained attention, and executive control. These findings suggest that FD seems to affect decoding skills that are required during reading, i.e., the non-lexical reading process in the dual route model of reading (Coltheart, Rastle, Perry, Langdon, & Zeigler, 2001), and is relatively independent of the lexical reading process, or sight word reading. Also, FD seems to be independent of language, attention, and executive control.

STUDY 2 sought to investigate the outcomes of two intervention programs in children with APD, when administered in isolation or in combination. The interventions were: 1) a bottom-up intervention program to improve FD - the FD intervention (McArthur et al., 2008), and 2) a top-

down intervention program to improve PP - the PP intervention (Rajkowski, 2003). An important focus of this study was to investigate whether prior FD intervention would enhance the outcome of the subsequent PP intervention. Generalisation of potential intervention effects of both intervention programs was also studied: 1) generalisation to another task that involved the same ability targeted during intervention, and 2) generalisation to overall language and reading abilities.

Nineteen children with FD and PP difficulties (aged 7;5 years to 9;9 years), who were also diagnosed with APD, were randomly allocated to one of four groups: 1) a group that undertook six weeks of FD intervention followed by six weeks of PP intervention – the FD-PP group; 2) a group that undertook six weeks of visual discrimination intervention (VD intervention)[1] followed by six weeks of PP intervention – the VD-PP group; 3) a group that undertook six weeks of PP intervention with no prior interventions – the PP group; and 4) a no-intervention control group – the CON group.

The findings showed that FD intervention resulted in significant intervention-specific improvement. However, there was no generalisation to a similar task of FD, or to language and reading abilities. PP intervention also resulted in significant intervention-specific improvement. There was partial support for the generalisation to a similar PP task and non-word reading. However, there was no generalisation to regular word reading, irregular word reading and language comprehension. Interestingly, when combined with prior FD intervention, significant generalisation of the PP intervention effect was observed for phonological awareness, non-word, and regular word reading. Therefore, the results demonstrate that prior FD intervention had enhanced the PP intervention outcome for the measures that are related to the non-lexical reading process.

In conclusion, the present findings support the assertion that FD might affect the non-lexical reading process. Prior remediation of FD difficulty could enhance the effect of subsequent reading-related interventions for non-lexical reading. These findings support the recommendation that interventions for APD should incorporate both bottom-up and top-down interventions.

[1] The VD intervention was included as an active comparison to the FD intervention but in the visual modality.

# 1 INTRODUCTION

Auditory Processing Disorder (APD) is a complex and heterogeneous disorder. Children with APD often present with difficulties in following directions, listen in the presence of background noise, and understanding degraded speech among other listening difficulties (see Jerger & Musiek, 2000 for details). These have a detrimental effect on classroom learning where students are expected to listen and learn in environments with background noise and other distractions. Hence, APD might hinder academic achievement. APD frequently coexists with other developmental impairments, such as language, reading, attention, and learning difficulties. It is estimated that APD occurs in 2% to 5% of children, with a 2:1 ratio between boys and girls (ASHA, 2005; Chermak, 2001; Moore, 2012). Based on these prevalence data and the estimated number of children in the Australian school system from the Australian Bureau of Statistics (2013), 177,000 to 355,000 children in Australia may have APD. Due to the potential detrimental effect of APD on children's language and academic development, it is imperative that these children are offered effective interventions.

Current recommendations are that interventions for APD should consist of both 'top-down' and 'bottom- up' therapy approaches (ASHA, 2005; Bellis, 2002; Chermak & Musiek, 1997; Friel-Patti, 1999). The 'top-down' approach, i.e., language-based auditory processing (AP) interventions, focuses on strengthening literacy and language skills, and the use of compensatory metalinguistic and metacognitive strategies (ASHA, 2005; Chermak & Musiek, 1997). The 'bottom-up' approach aims to remediate the underlying AP deficits with the assumption that AP difficulties may also be a contributing factor to language and literacy impairment (Ellis-Weismer, 2005). Hence, training and improvement in AP/perceptual skills may drive improvements in the acquisition of higher-level skills.

However, current clinical practice in speech pathology does not often include AP training. It is imperative to have a better understanding of the role that perceptual abilities play in reading and language (which are key skills contributing to children's academic achievement), and whether the inclusion of perceptual training is beneficial. Currently, there is only limited research on the potential impact that non-speech AP training might have on the outcomes of reading and language interventions in children with APD.

The influence of poor AP in the context of a particular AP ability, namely auditory frequency discrimination (FD), was investigated in the present thesis. In recent years, FD has emerged as an important auditory process, in that it has been repeatedly shown to be associated with reading and language difficulties. Poor FD ability in individuals with specific language impairment (SLI) and specific reading disorders (SRD) has been reported in many studies (Ahissar, Protopapas, Reid, & Merzenich, 2000; Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999; De Weirdt, 1988; Halliday & Bishop, 2006; Hill, Hogben, & Bishop, 2005; McArthur & Bishop, 2004; Mengler, Hogben, Michie, & Bishop, 2005; Talcott et al., 2002). However, the proposition that improving FD ability could lead to enhanced outcomes of subsequent top-down interventions remains largely unexplored. This thesis consists of two studies addressing this issue. STUDY 1 focused on investigating whether children with APD who also demonstrated FD difficulty, would have poorer phonological processing, word reading, receptive language, auditory-sustained attention and executive control than children with APD and age-appropriate FD; and STUDY 2 which is concerned with whether prior FD intervention might enhance the effect of the subsequent phonological processing (PP) intervention aimed to improve reading for this population.

# 2 LITERATURE REVIEW

## 2.1 APD: Presenting Symptoms and Definition

A number of definitions of APD have been proposed over recent decades. The most frequently cited definition was published in a technical report by the American Speech and Hearing Association (ASHA, 2005). ASHA states that APD may be defined as an impairment in "the neural processing of auditory stimuli that is not due to higher order cognitive functions such as language, attention, memory, auditory synthesis" (pp. 2), and that "AP may include the following abilities or skills: sound localisation and lateralisation, auditory discrimination, auditory pattern recognition, the temporal aspects of audition (including temporal integration, temporal discrimination - e.g., temporal gap detection, temporal ordering, and temporal masking), auditory performance in competing acoustic signals (including dichotic listening), and auditory performance with degraded acoustic signals" (pp. 2).

More recently, the British Society of Audiology (BSA) published a position paper on APD (BSA, 2011). Wilson and Arnott (2012) suggest that the key point of contrast with the ASHA definition is that the BSA states that APD is characterised by poor perception of non-speech **and** speech stimuli, while according to the ASHA definition, APD can affect non-speech **and/ or** speech sounds.

Another difference between ASHA and BSA definitions of APD is that ASHA views APD as a predominantly bottom-up sensory processing impairment, and that top-down modulation by cognitive functions such as attention is a confound to be controlled for in APD assessments. The BSA's definition explicitly states that attention is a key element that influences AP, and poor attention plays a major role in APD. It is argued that APD is a neurological impairment that may stem from the processing deficiency of both the afferent and the efferent pathways in the auditory nervous system, and hence can be affected by both top-down and bottom-up processes.

The differences in definition have direct clinical implications for how APD 'should' be diagnosed. For instance, based on the BSA definition, the criterion for a positive APD diagnosis requires poor performance on at least two audiological tests, one that involves non-speech stimuli and the other involving speech stimuli. ASHA recommends that the APD test battery should generally include both speech and non-speech tests but failure on speech based test is not a mandatory requirement for APD. The differences in the ASHA and BSA definition also have implications for APD intervention approaches. For instance, BSA states that "APD presents as impaired perception of **both** non-speech and speech sounds, and is closely associated with impaired top-down, cognitive function" (pp. 6), which might implied that APD can be directly addressed through top-down interventions, whereas ASHA views top-down interventions as mainly compensatory as compared to the direct remedial effects of bottom-up interventions that target the specific AP deficits.

The debate regarding the nature of APD continues, reflecting the complexity and heterogeneity that is inherent in the nature of the disorder, and possibly, in its aetiology. Similar position papers have been published by the American Academy of Audiology (AAA, 2010) and the Canadian Interorganisational Steering Group for Speech-Language Pathology and Audiology (2012). Further discussion of the nature of APD goes beyond the focus of the current thesis (see Wilson and Arnott (2012) for more details on this topic).

## 2.2 Direct Intervention for APD: A systematic review

There is general consensus in the literature that direct intervention, along with environmental modification and acoustic enhancement, comprise a comprehensive management program for children with APD (AAA, 2010; ASHA, 2005; BSA, British Society of Audiology, 2011; Chermak, Hall, & Musiek, 1999; Chermak & Musiek, 2007). It has been recommended that direct APD intervention should consist of two types of approaches: 1) bottom-up approaches, i.e., in particular, auditory perceptual training or auditory training; and 2) top-down approaches that include the training of language, cognitive and metacognitive strategies (Chermak et al., 1999; Chermak & Musiek, 2007). Bottom-up approaches aim to improve basic AP abilities through the plasticity of the central auditory nervous system (Chermak & Musiek, 1997; Tremblay & Kraus, 2002). The theory underpinning this would suggest that through the appropriate auditory stimulation, the neuronal connections are remapped and more efficient synaptic connections are formed. This, in turn, produces desirable behavioural changes (Chermak & Musiek, 2007; Musiek, Shinn, & Hare, 2002). In contrast, top-down approaches focus on the strengthening of cognitive abilities, such as language and literacy abilities. These are beneficial as language and literacy difficulties often co-exist with APD. The training of these cognitive skills can help the child to compensate for difficulties in AP (ASHA, 2005; BSA, British Society of Audiology, 2011; Chermak et al., 1999; Chermak & Musiek, 2007).

Environmental modification and acoustic enhancement are also important to APD management. However, such approaches are not the focus of the present study. A review of the literature related to these topics is beyond the scope of this thesis (see Crandell & Smaldino, 1995; Johnston, John, Kreisman, Hall III, & Crandell, 2009; Kuk, Jackson, Keenan, & Lau, 2008; Lemos et al., 2009; Rosenberg, 2002 for more details).

To date, there is a small body of research investigating the effectiveness of direct APD intervention. In order to further our understanding of the contribution of bottom-up and top-down approaches to intervention outcomes, it is necessary to consider and compare the effects of both approaches. In particular, it would be of interest to investigate whether the interventions have any significant effects on the AP skills that were being targeted by the interventions (i.e., intervention-specific effects), and whether they have any significant effects on broader abilities, such as language and literacy abilities (i.e., generalisation effects). Therefore, a systematic search of the literature was conducted with a focus on the following questions:

1) Do bottom-up approaches in APD intervention result in significant intervention-specific and generalisation effects in children with APD?
2) Do to-down approaches in APD intervention result in significant intervention-specific and generalisation effects in children with APD?

### 2.2.1 Methods

A systematic search was conducted for peer-reviewed articles published from 1990 to 2012 using five databases: Medline, PsychInfo, Eric, Informit, and Google Scholar. The key terms used were ‘central auditory processing disorder’, ‘auditory processing disorder’ or ‘auditory perceptual disorder’, combined with either ‘intervention’, ‘management’, ‘treatment’, ‘training’ or ‘therapy’. Only empirical studies that were published in English were included. Additionally, studies were excluded when the participants were described as solely having reading, language and learning disorders in the absence of APD or suspected APD. For the purpose of this review, ‘bottom-up’ approaches were defined as interventions that target basic AP abilities that involve the progressive manipulation of the acoustic or auditory features of the stimuli to achieve an intervention outcome. The stimuli used could be linguistic or non-linguistic in nature. ‘Top-down’ approaches were defined as language or literacy-based interventions, in which the language or literacy content was manipulated rather than acoustic components. Due to the disagreement concerning the nature of APD, this review included all intervention studies that involved school-age children with a diagnosis of APD or suspected APD, regardless of the specific diagnostic criteria used. A similar approach has been used in a previous systematic review concerning the APD population (Fey et al., 2011).

Each eligible study was rated in terms of the levels of evidence documented in the guidelines of the Scottish Intercollegiate Guideline Network (SIGN, 2011) (see Table 2.1) – an earlier version of this guideline (SIGN, 2002) was quoted in ASHA (2004b).

**Table 2.1: Levels of evidence adapted from the guidelines of the Scottish Intercollegiate Guideline Network (Scottish Intercollegiate Guidelines Network, 2011)**

| **Levels of evidence** | |
|---|---|
| **Ia** | High quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias |
| **Ib** | Meta-analyses, systematic reviews, or RCTs with a |

| | |
|---|---|
| | high risk of bias |
| **Ic** | High quality systematic reviews of case control or cohort studies |
| **IIa** | Well conducted case control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal |
| **IIb** | Case control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not causal |
| **III** | Non-analytic studies, e.g., case reports, case series |
| **IV** | Expert opinion |

The eligible studies were also evaluated for methodological quality based on the quality indicators recommended by the National Health and Medical Research Council (NHMRC, 2000a, 2000b) and the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green, 2009). The quality indicators used included: an adequate description of the study design and protocol, random allocation, blinding, intervention fidelity, significance testing, reporting of effect sizes, absence of selective reporting, the handling of incomplete data, and the use of the intention to treat analysis. Additionally, adhering to these recommendations, one point was awarded for each specific quality indicator that was met in the paper, using the following criteria:

- **Study protocol**: there are adequate details describing the design of the study so that the study can be replicated;
- **Random allocation**: the participants were randomly assigned to groups;
- **Blinding**: the researchers were blinded to the participant’s allocated group or training status (i.e., whether training had been undertaken by the participant at the point of the assessment);
- **Intervention fidelity**: processes or protocols were in place to ensure that the described intervention was implemented accordingly;
- **Significance testing**: pre- and post-intervention analyses or between-group comparisons were conducted for the main intervention effects;

- **Reporting of effect sizes**: effect size of the intervention effects were reported along with their respective confidence intervals;
- **Selective reporting**: all of the study's pre-specified outcomes that are of interest in the review were reported;
- **Handling of incomplete data**: there were no missing outcome data; or the reasons for missing outcome data were unlikely to be related to true outcomes; or missing data were addressed using appropriate methods;
- **Intention to treat**: the participants were analysed according to the group to which they were initially randomly allocated to, regardless of whether or not they dropped out, fully complied with treatment, or crossed over and received the other treatment.

Systematic reviews were appraised based on the following quality indicators from the NHMRC (2000b):

- **Study protocol**: there are adequate details describing the review process so that it can be replicated;
- **Search strategies**: an adequate search strategy was used;
- **Inclusion criteria**: appropriate inclusion criteria were applied in an unbiased way;
- **Quality assessment**: a quality assessment of the included studies was undertaken;
- **Blinding**: each eligible study was rated by multiple reviewers who were blinded to each other's ratings;
- **Individual studies summarised**: the characteristics and results of the individual studies were appropriately summarised;
- **Pooling of data**: the method of pooling the data was appropriate;
- **Heterogeneity explored**: sources of heterogeneity between the studies were explored.

Studies that were experimental and quasi-experimental, which attempted to determine whether an intervention resulted in a particular outcome, could obtain a maximum of nine points. Studies that were exploratory in nature, i.e., case-control studies, single group designs, or case studies, could obtain a maximum of seven points. This is because random allocation and the use of 'intention to treat' analysis would be irrelevant for these study designs. Finally, systematic reviews could receive a maximum of eight points.

### 2.2.2 Results

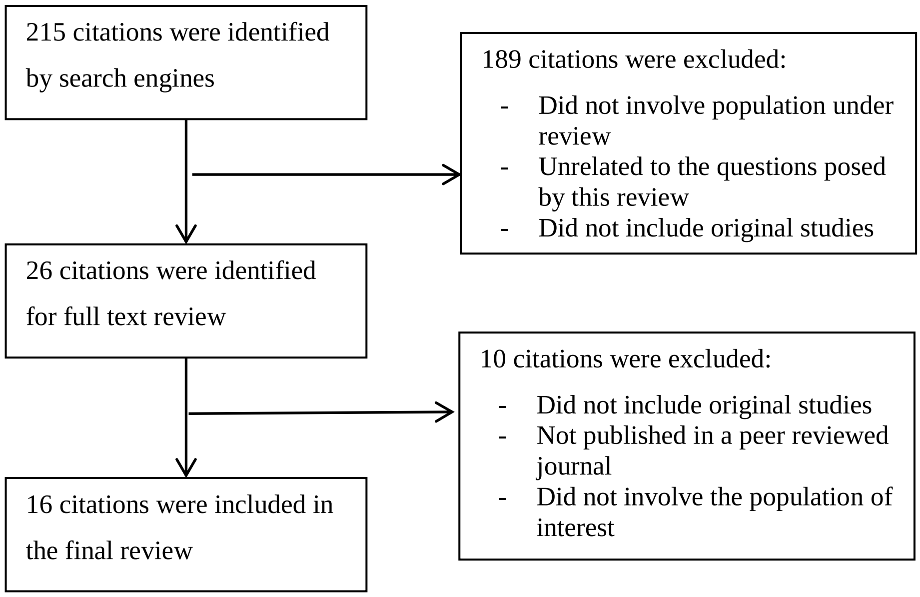


**Figure 2.1: Flow chart of the identification process of articles for review**

The findings from the initial systematic search are provided in Figure 2.1. A total of 215 citations were identified and evaluated based on their titles and abstracts. Of these, 26 were initially accepted. Upon review of the full text of these articles, ten of the 26 studies were rejected, detail as follows: 1) one was not published in a peer-reviewed journal (Stephenson, 2008), 2) eight did not explicitly state that the participants had APD or were suspected of having APD (Deppeler, Taranto, & Bench, 2004; Gaab, Gabrieli, Deutsch, Tallal, & Temple, 2007; Gillam et al., 2008; Given, Wasserman, Chari, Beattie, & Eden, 2008; Kujala et al., 2001; Loo, Bamiou, Campbell, & Luxon, 2010; Stevens, Fanning, Coch, Sanders, & Neuille, 2008; Veuillet, Magnan, Ecalle, Thai-Van, &

Collet, 2007), and 3) one included participants who were not school age children (Schäffler, Sonntag, Hartnegg, & Fischer, 2004)

A total of 17 studies published in 16 citations met the selection criteria (Alonso & Schochat, 2009; Cameron & Dillon, 2011; Cameron, Glyde, & Dillon, 2012; English, Martonik, & Moir, 2003; Fey et al., 2011; Gaab et al., 2007; Jirsa, 1992; Leitao, 2003; McArthur et al., 2008; Miller et al., 2005; Moncrieff & Wertz, 2008; Putter-Katz, Adi-Bensaid, Feldman, & Hildesheimer, 2008; Putter-Katz et al., 2002; Schochat, Musiek, Alonso, & Ogata, 2010; Sharma, Purdy, & Kelly, 2012; Yencer, 1998). Of these, six studies (Alonso & Schochat, 2009; Gaab et al., 2007; Jirsa, 1992; Putter-Katz et al., 2008; Putter-Katz et al., 2002; Schochat et al., 2010) employed interventions that incorporated both bottom-up and top-down approaches; seven studies published in six citations (Cameron & Dillon, 2011; Cameron et al., 2012; English et al., 2003; McArthur et al., 2008; Moncrieff & Wertz, 2008; Yencer, 1998) investigated the effectiveness of bottom-up APD approaches, one explored the use of top-down approaches (Leitao, 2003), and three studies compared the effectiveness of bottom-up and top-down approaches (Fey et al., 2011; Miller et al., 2005; Sharma et al., 2012).

Table 2.2, Table 2.4, Table 2.6, and Table 2.8 display a summary of these studies, i.e., the criteria for participant selection, the age group of the participants, the number of participants, types of intervention, intervention schedule and duration, and study outcomes in terms of AP, literacy language ability. Table 2.3, Table 2.5, Table 2.7, and Table 2.9 summarise the levels of evidence and the methodological qualities of these studies. The presence and direction of statistically significant comparisons and effects are reported in the tables with the following codes:

1) '+' indicates that the study contained/showed at least one statistically significant outcome ($\alpha = 0.05$) in favour of the intervention studied. This could have been obtained based on pre- and post-intervention comparisons, or between-group comparisons with the control group;
2) '0' indicates the reporting of one or more non-statistically significant outcomes; and

3) '-' indicates that there was one or more negative outcome(s), i.e., there was significantly poorer post-intervention performance in at least one measure. Studies that employed more than one outcome measure for a particular intervention were eligible for all three signs.

### 2.2.3 Discussion

#### *2.2.3.1 Intervention-specific and generalisation effect of the integrated top-down and bottom-up approaches*

A systematic search of the literature revealed six studies (Alonso & Schochat, 2009; Gaab et al., 2007; Jirsa, 1992; Putter-Katz et al., 2008; Putter-Katz et al., 2002; Schochat et al., 2010) that addressed the effectiveness of APD interventions that integrated both the bottom-up and the top-down approaches[2]. In total, 151 children with APD and 65 children without APD participated in these studies. Table 2.2 displays a summary of these studies and Table 2.3 displays their methodological appraisal.

These studies provide some support of the effectiveness of the integrated 'top-down' and 'bottom-up' approach in APD intervention. All six studies reported significant improvement on at least some, if not all, AP measures following training. Alonso and Schochat (2009) reported significant post-intervention improvement on measures of synthetic sentence identification with ipsilateral competing message, speech in noise, directed attention non-verbal dichotic listening and staggered spondaic word in a group of 29 children (8 to 16 years) who undertook auditory training.

[2] The details of the intervention in one of the studies, Alonso and Schochat (2009), were not clearly described. However, the authors stated that the intervention was based on the recommendations of references that advocated a combined 'bottom-up' and 'top-down' approach to APD intervention.

**Table 2.2: Summary of studies that investigated the effectiveness of intergrated top-down and bottom-up approaches (page 1 of 3)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech, or both) | Improved AP? | Improved language or literacy? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|
| **(Putter-Katz et al., 2002)** | APD: < 1SD below mean on either ear in a battery of AP tests | 7;11-14;4 | 20 APD | Comprehension in noise, dichotic listening, selective & divided attention, FM, auditory closure, speech reading, metacognitive awareness, listening strategies (20) | 45 min 1 per week 4 months 13-15 sessions | Speech | + | NT | NR |
| **(Putter-Katz et al., 2008)** | APD: < 1SD below mean on either ear in a battery of AP tests | 7;11-14;4 | 30 APD | Comprehension in noise, dichotic listening, selective & divided attention, FM, auditory closure, speech reading, metacognitive awareness, listening strategies (20)<br>NI (10) | 45 min 1 per week 4 months 13-15 sessions | Speech | + | NT | NR |
| **(Alonso & Schochat, 2009)** | APD: altered results on two tests out of a battery of AP tests | 8;0-16;0 | 29 APD | Unclear (29) | 50 min 1 per week 8 weeks | Unclear | + | NT | 0 |

**Table 2.2 (CONT): Summary of studies that investigated the effectiveness of integrated top-down and bottom-up approaches (page 2 of 3)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech, or both) | Improved AP? | Improved language or literacy? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|
| **(Gaab et al., 2007)** | APD: poorer pitch discrimination than controls that was trending towards a sig diff (*p* = 0.051) | M (SD) = 10.8 (0.9) SRD<br>M (SD) = 10.5 (1.9) Typical readers | 22 SRD<br>23 Typical readers | FFW (22 APD + SRD)<br>CON (23 Typical readers) | 20 mins<br>5 per week<br>8 weeks | Speech | -, + | +, 0 | NR |
| **(Jirsa, 1992)** | APD: abnormal result on at least one of three AP tests (SAAT, CST, and RAS). | 9;5-12;5 | 20 APD<br>20 Typical | Auditory memory, competing noise, auditory attention, and language comprehension (10)<br>NI (10 APD)<br>NI (20 Typical) | 45min<br>2 per week<br>14 weeks | Speech | +, 0 | NT | +, 0 |

**Table 2.2 (CONT): Summary of studies that investigated the effectiveness of integrated top-down and bottom-up approaches (page 3 of 3)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech, or both) | Improved AP? | Improved language or literacy? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|
| **(Schochat et al., 2010)** | APD: below normal performance in at least one ear for two AP tests | 8;0-14;0 | 30 APD<br><br>22 Typical | Training of frequency, intensity, temporal, dichotic, localisation and speech perception, and language activities (30)<br><br>NI (22) | 50 min<br>1 per week<br>8 weeks<br><br>15 min of daily home exercise | Both | +, 0 | NT | NR |

KEY: Tx = Training; NT = Not tested; NR = Not reported; '+' = one or more effects favoured the treatment, '0' = one or more non-significant treatment effects, and '–' = one or more effects favouring the pre-intervention measurement or controls; SAAT = the Selective Auditory Attention Competing Subtest (Cherry, 1980); CST = the Competing Sentences Test (Willeford, 1977); RAS = Rapidly Alternating Speech Test (Willeford, 1977); NI = No Intervention; Tx = Training; NT = Not tested; NR = Not reported; '+' = one or more effects favoured the treatment, '0' = one or more non-significant treatment effects, and '–' = one or more effects favouring the pre-intervention measurement or controls.

**Table 2.3: Levels of evidence and the methodology assessment of the studies that investigated the effectiveness of the integrated bottom-up and top-down approaches (page 1 of 2)**

| Reference | Levels of Evidence (quality points awarded) | Study protocol | Blinding? | Random allocation? | Interventio n fidelity? | Sig. testing | Reporting of Effect sizes | Incomplete outcome data addressed? | Intention to treat? | Free of selective reporting? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Putter-Katz et al., 2002)** | III (2/7) | Inadequate | No | N/A | No | Yes | No | Unclear | N/A | Yes |
| **(Putter-Katz et al., 2008)** | IIb (2/7) | Inadequate | No | N/A | No | Yes | No | Unclear | N/A | Yes |
| **(Schochat et al., 2010)** | IIb (3/7) | Adequate | No | N/A | No | Yes | No | Unclear | N/A | Yes |
| **(Alonso & Schochat, 2009)** | III (3/7) | Inadequate | No | N/A | No | Yes | Yes | Unclear | N/A | Yes |
| **(Gaab et al., 2007)** | IIa (4/7) | Adequate | No | N/A | Yes | Yes | No | No | N/A | Yes |

**Table 2.3 (CONT): Levels of evidence and the methodology assessment of the studies that investigated the effectiveness of the integrated bottom-up and top-down approaches (page 2 of 2)**

| Reference | Levels of Evidence (quality points awarded) | Study protocol | Blinding? | Random allocation? | Interventio n fidelity? | Sig. testing | Reporting of Effect sizes | Incomplete outcome data addressed? | Intention to treat? | Free of selective reporting? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Putter-Katz et al., 2002)** | III (2/7) | Inadequate | No | N/A | No | Yes | No | Unclear | N/A | Yes |
| **(Putter-Katz et al., 2008)** | IIb (2/8) | Inadequate | No | No | No | Yes | No | Unclear | No | Yes |
| **(Schochat et al., 2010)** | IIb (2/7) | Inadequate | No | N/A | No | Yes | No | Unclear | N/A | Yes |
| **(Alonso & Schochat, 2009)** | III (3/7) | Inadequate | No | N/A | No | Yes | Yes | Unclear | N/A | Yes |
| **(Jirsa, 1992)** | IIa (5/9) | Inadequate | No | Yes | Yes | Yes | Yes | Yes | No | No |

**Table 2.4: Summary of studies that investigated the effectiveness of bottom-up approaches (page 1 of 3)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech or both) | Improved AP? | Improved language or literacy? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|
| **(Cameron & Dillon, 2011)** | Suspected APD and < 2SD on the LiSN-S | 6;9-11;4 | 9 APD | LiSN & Learn (Cameron & Dillon, 2010) (9) | 2 games per day<br>5 days per week until the completion of 120 games (approx. 15-20 min per day for 3 months) | Speech | + | NT | NR |
| **(Cameron et al., 2012)** | Suspected APD and performance outside the normal limits on LiSN-S | 6;0-9;6 | 10 APD | LiSN & Learn (5)<br>Earobics (5) | 2 games per day<br>5 days per week until the completion of 120 games (approx. 15-20 min per day for 3 months) | Speech | + | NT | ES reported but not CI |
| **(English et al., 2003)** | Suspected APD and Reduced left-ear score on DDT | 5;10-10;9 | 10 APD | Dichotic Listening (10) | 1hr<br>1 per week<br>10-13 weeks | Speech | NT* | NT | NR |

**Table 2.4 (CONT): Summary of studies that investigated the effectiveness of bottom-up approaches (page 2 of 3)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech or both) | Improved AP? | Improved language or literacy? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|
| **(McArthur et al., 2008)** | APD: atypical performance on RAP, FD, VD and CVD | 6;0-15;11 | 28 APD + SRD/SLI | FD (18)<br>RAP (3)<br>VD (4)<br>CV (9)* | 20 min<br>4 per week<br>6 weeks | Non-speech or simple speech | + | 0 | NR |
| **(Moncrieff & Wertz, 2008): Study 1** | APD: Poor left ear score on DDT | 7;0-13;0 | 8 APD | Dichotic Listening | 30 min<br>3 per week<br>4 weeks<br>11 sessions | Speech | +, 0 | NR | NR |
| **(Moncrieff & Wertz, 2008): Study 2** | APD: Poor left ear score on DDT | 6;4-11;0 | 10 APD<br>3 No APD | Dichotic Listening of different durations (13) | 30 min<br>4 per week<br>3 weeks (n=2)<br>4 weeks (n=4)<br>6 weeks (n=7) | Speech | + | +, 0 | NR |

**Table 2.4 (CONT): Summary of studies that investigated the effectiveness of bottom-up approaches (page 3 of 3)**

| **Reference** | **APD diagnostic criteria/ selection criteria** | **Age (year; month)** | **N** | **Experimental groups (n)** | **Schedule** | **Tx Stimuli (non-speech, speech or both)** | **Improved AP?** | **Improved language or literacy?** | **Sig. effect?** |
|---|---|---|---|---|---|---|---|---|---|
| **(Yencer, 1998)** | APD: > 1SD below mean on either ear in a battery of AP tests | Grades 1-4 | 36 APD | MAIT<br>Unaltered music<br>NI<br>NOTE: n per group not specified. | 30 min<br>2 x per day<br>10 days | Non-speech | 0 | NT | NR |

Key: DDT = the Dichotic Digit Test; LiSN-S = Listening in spatialised noise – sentence test; MAIT = Modified Auditory Integration Training; NI = No Intervention; CIN = Comprehension in noise; ES = Effect Size; CI = Confidence Interval; Tx = Training; NT = Not tested; NR = Not reported; '+' = one or more effects favoured the treatment, '0' = one or more non-significant treatment effects, and '–' = one or more effects favouring the pre-intervention measurement or controls.

* No statistical testing was conducted. However, all participants' left ear scores on the dichotic test improved at least 1.5 SDs; 9 participants improved their left ear scores to be within age norms.

**Table 2.5: Levels of evidence and the methodological assessment of the studies that investigated the effectiveness of bottom-up approaches**

| Reference | Levels of Evidence (quality points awarded) | Study protocol | Blinding? | Random allocation? | Intervention fidelity? | Sig. testing | Reporting of effect sizes | Incomplete outcome data addressed? | Intention to treat? | Free of selective reporting? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Cameron & Dillon, 2011)** | III (4/7) | Adequate | No | N/A | Yes | Yes | NR | Unclear | N/A | Yes |
| **(Cameron et al., 2012)** | Ia (8/9) | Adequate | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes |
| **(English et al., 2003)** | III (1/7) | Adequate | No | N/A | No | No | NR | Unclear | N/A | No |
| **(McArthur et al., 2008)** | IIa (5/7) | Adequate | No | N/A | Yes | Yes | NR | Yes | N/A | Yes |
| **(Moncrieff & Wertz, 2008): Study 1** | III (1/7) | Inadequate | No | N/A | No | Yes | NR | Unclear | N/A | No |
| **(Moncrieff & Wertz, 2008): Study 2** | IIb (2/7) | Inadequate | No | N/A | No | Yes | NR | No | N/A | Yes |
| **(Yencer, 1998)** | IIa (5/9) | Adequate | Yes | No | Yes | Yes | NR | Unclear | No | Yes |

**Table 2.6: Summary of the study that investigated the effectiveness of top-down approaches**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech or both) | Improved AP? | Improved language or literacy? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|
| **(Leitao, 2003)** | Poor speech-in-noise and short-term memory difficulties | 8;6 | 1 | Psycholinguistic Tx (1) | NR | Speech | NT | NT* | NR |

KEY: Tx = Training or treatment; NR = Not reported; NT = Not tested; '+' = one or more effects favoured the treatment, '0' = one or more non-significant treatment effects, and '–' = one or more effects favouring the pre-intervention measurement or controls.

*No statistical testing was conducted. Literacy scores were below average prior to intervention and fell within the normal limits post-intervention.

**Table 2.7: Levels of evidence and the methodological assessment of the study that investigated the effectiveness of top-down approaches**

| Reference | Levels of Evidence (quality points awarded) | Study protocol | Blinding? | Random allocation? | Interventio n fidelity? | Sig. testing | Reporting of effect sizes | Incomplete outcome data addressed? | Intentio n to treat? | Free of selective reporting? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Leitao, 2003)** | III (0/7) | Inadequate | No | N/A | No | No | No | Unclear | N/A | No |

**Table 2.8: Summary of studies that compared the effectiveness of bottom-up and top-down approaches (page 1 of 2)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech or both) | Improved AP? | Improved lang. or lit.? | Sig effect ? |
|---|---|---|---|---|---|---|---|---|---|
| **(Miller et al., 2005)** | Suspected APD: Unclear criteria | 7;0-9;0 | 7 Suspected APD | Fast ForWord (3) | 100 mins 5 x per weeks | Speech | +, 0 | +, - (lit. only) | NR |
| | | | | Earobics (2) | | | +, 0 | +, 0 (lit. only) | |
| | | | | AT incl. auditory memory, auditory discrimination, auditory closure, auditory synthesis, auditory figure ground and auditory multisensory integration (2) | 4 weeks 20 sessions | | +, 0 | +, 0 (lit. only) | |
| **(Sharma et al., 2012)** | Suspected APD | 9;0-12;0 | 55 Suspected APD | Discim* (5) | 1 hour 1 per week 6 weeks | Both | + | +, 0 | +, 0 |
| | | | | Discrim + FM (7) | | Both | 0 | +, 0 | +, 0 |
| | | | | Lang** (10) | | Speech | + | +, 0 | +, 0 |
| | | | | Lang + FM (10) | 15 min of daily home exercise | Speech | 0 | +, 0 | +, 0 |
| | | | | NI (8) | | | | (lang. and lit.) | |

**Table 2.8 (CONT): Summary of studies that compared the effectiveness of bottom-up and top-down approaches (page 2 of 2)**

| Reference | APD diagnostic criteria/ selection criteria | Age (year; month) | N | Experimental groups (n) | Schedule | Tx Stimuli (non-speech, speech or both) | Improved AP? | Improved language or literacy? | Sig. effect ? |
|---|---|---|---|---|---|---|---|---|---|
| **Systematic Review** | | | | | | | | | |
| **(Fey et al., 2011)** | APD: based on teachers concerns for listening difficulties or low performance on one of a battery of AP tests | School-aged children | 121 APD | AT incl. speech-in-noise training, auditory recognition, and auditory discrimination to improve comprehension (see individual studies for details) (87) | Depending on various studies | Both | +, 0 | NT | NR |
| | | | | Fast ForWord (3) | | Both | +, 0 | +, - (literacy) | |
| | | | | Earobics (2) | | Speech | +, 0 | +, 0 (literacy) | |
| | | | | Modified AIT (29) | | Non-speech | 0 | NT | |

KEY: AT = Auditory training; AIT = Auditory integration training; Discrim = Discrimination; Lang = Language; FM = Frequency Modulated Assistive Listening Devices; NT = Not tested; NI = No intervention; NR = Not reported; '+' = one or more effects favoured the treatment, '0' = one or more non-significant treatment effects, and '–' = one or more effects favouring the pre-intervention measurement or controls.

* Discrimination training incl. gap detection, frequency discrimination, intensity discrimination, identification of syllables, segmenting words, rhyming, and reading aloud.

** Lang intervention incl. following directions, scrambled sentences, rhythm building, circumlocution, building a story with pictures, summarising short stories, identification of key words in sentences, sentence comprehension based on stress patterns, visualisation and rehearsal, and reading aloud.

**Table 2.9: :Levels of evidence and the methodological assessment of the studies that compared the effectiveness of bottom-up and top-down approaches**

| Reference | Levels of Evidence (quality points awarded) | Study protocol | Blinding? | Random allocation? | Interventio n fidelity? | Sig. testing | Reporting of effect sizes | Incomplete outcome data addressed? | Intenti on to treat? | Free of selective reportin g? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Miller et al., 2005)** | III (2/7) | Adequate | N/A | No | No | Yes | No | Unclear | N/A | No |
| **(Sharma et al., 2012)** | Ia (4/9) | Adequate | No | Yes | No | Yes | No | Unclear | No | Yes |

**Systematic Review**

| | Levels of Evidence (quality points awarded) | Study protocol | Search Strategies | Inclusion criteria appropriate? | Quality assessment undertaken ? | Blinding? | Individual study summaris ed? | Methods of pooling data? | Heterogeneity explored? |
|---|---|---|---|---|---|---|---|---|---|
| **(Fey et al., 2011)** | Ic (7/8) | Adequate | Yes | Yes | Yes | Yes | Yes | No | Yes |

Alonso and Schochat (2009) also reported increased latency of the P300 event related potential (ERP). The details of what comprised the auditory training were not given but references were made to citations that advocated an integrated bottom-up and top-down approach to direct APD intervention (Chermak & Musiek, 1992; Musiek & Chermak, 1995; Musiek & Schochat, 1998).

This study provided level III evidence and received a methodological rating of 3/7. The major limitations were that the study protocol was not adequately documented and the methods of ensuring intervention fidelity were either not in place or not described clearly, and hence, it would be difficult to replicate its findings. Additionally, because the study did not include a no-intervention control group, the effects of experimental confounds such as the test-retest effect, the Hawthorne effect, and maturation could not be ruled out. Hence the observed effects could not be ascribed to the intervention with confidence.[3]

Schochat et al. (2010) reported significant improvement in the pre-and post-intervention performance of the paediatric speech intelligibility (PSI) test (Jerger & Jerger, 1984), the speech-in-noise test (Pereira & Schochat, 1997), the staggered spondaic word test (SSW) (Katz, 1968), the dichotic digits test (Musiek, 1983), and a dichotic nonverbal test (Pereira & Schochat, 1997) in a group of 30 children with APD (age 8-14 years). There was also significant increase in the amplitude of the middle latency response. No significant changes in performance were observed in a group of 22 age-typical controls who did not undergo any intervention but were assessed and reassessed over the same time frame as the APD intervention group. The intervention included bottom-up interventions that targeted the discrimination of frequency, intensity, temporal, dichotic,

[3] The importance of including a no-intervention control group in studies that investigate intervention effectiveness is demonstrated in a study conducted by Gillam et al. (2008). Gillam and associates conducted a blinded, randomised controlled trial involving 216 children with language impairment (age 6-9 years). They compared the auditory processing and language outcomes of four experimental conditions: 1) the Fast ForWord program (a language intervention that utilises acoustically-modified speech for language remediation); 2) a computer-assisted language intervention that did not involve modified speech; 3) a computer-assisted academic enrichment program that did not focus on language but focused on mathematics, science, and geography; and 4) individual therapist-assisted language intervention. Their results show that all four conditions resulted in similar and significant improvement in language and AP ability, even for Condition 3 that did not focus on teaching language. A possible explanation provided by the authors was that attention had been enhanced due to the intensive exposure to the training programs regardless of the type of training undertaken. This had a positive effect on performance during the subsequent assessment sessions across all conditions. However, because a no-intervention control group was not included, hence, the effects of maturation, repeated testing, and Hawthorne could not be ruled out.

as well as sound localisation, and speech perception. The intervention was referred to as the ‘formal auditory training’ that required specialised equipment and the training took place in a soundproof room. The children in the APD intervention group undertook the formal auditory training 50 minutes per week for 8 weeks. The other part of the intervention program involved the top-down training of language comprehension. The activities included following directions, drawing to description, auditory memory of words and sentence recall. This was referred to as the ‘informal auditory training’ that took place at home and was delivered by parents. The children in the APD intervention group undertook the informal auditory training 15 mins daily for eight weeks.

This study provided level IIb evidence and received a methodological rating of 3/7. The results show that the auditory training program resulted in improvement in the intervention group that was greater than the test-retest effects observed in the no intervention group. However, it is uncertain whether the non-significant differences observed in the no-intervention group (that consisted of children without APD) would have reflected the potential test retest effect of these APD tests in the APD population. This is because there is the possibility that these children without APD were performing at, or very close to, the ceiling level on the tests during the initial and the subsequent assessment sessions. The findings of this study would have been strengthened if the no-intervention group consisted of children who also had APD. Another possible limitation of this study is that it would be difficult to maintain intervention fidelity of the informal auditory training (in terms of both the amount of intervention undertaken as well as what was being done). This might be of importance considering that the informal auditory training was actually the crux of the intervention program investigated by this study based on time allocation. The participants undertook 50 mins of the formal auditory training per week but 105 mins of the informal auditory training per week (15 mins x 7 days) if it was carried out according to the description in the paper. The amount of time for which the participants engaged in the informal auditory training was more than double the time they undertook the formal auditory training. Due to the fact that the informal auditory training took place at home and was delivered by parents, it would have been difficult to maintain intervention fidelity and to impose measures to reduce experimental confounds. This poses difficulty for future research in replicating this study.

Putter-Katz et al. (2002) documented significant post-intervention improvement in speech recognition in degraded listening condition following four weeks of AP intervention that targeted comprehension in noise, dichotic listening, selective and divided attention, auditory closure, speech reading, metacognitive awareness, listening strategies and the use of Frequency Modulated (FM) assistive listening devices. A group of 20 children with APD participated in the study. No further details of the intervention were given. This study provided level III evidence and received a methodological rating of 2/7. Again, the major limitations include an inadequate description of the intervention protocol and a lack of comparison with a no-intervention control group.

Putter-Katz et al. (2008) presented the original results published in Putter-Katz et al. (2002) and compared them with the performance of an no-intervention control group that consisted of children with APD who were also retested after a four week period. They found that the intervention group showed significant improvement on speech-in-noise and dichotic listening measures but there were no changes in performance in the control group. This study provided level IIb evidence, and a methological rating of 2/8. There is some evidence suggesting the effectiveness of the intervention in improving speech-in-noise and dichotic listening. However, the results could be confounded by experimenter biases as there was a lack of random allocation of the participants to the different experimental conditions and a lack of blinding. Again, measures to ensure intervention fidelity were either not in place or clearly described, and the inadequate documentation of their methodology would make replicatng the study difficult.

Gaab et al. (2007) investigated the effectiveness of the Fast ForWord–Language Program in remediating AP, reading and language difficulties in children with SRD. Twenty-two children with APD and SRD [mean (SD) for age = 10.8 (0.9)] and 23 children without SRD [mean (SD) for age = 10.5 (1.9)], who served as the control group, participated in the study. The SRD group was found to have poorer pitch discrimination that was trending towards a significant difference ($p = 0.051$)

when compared with the control group prior to the intervention. The Fast ForWord-Language program is an adaptive, computer based intervention program that targeted rapid auditory processing (RAP), phoneme discrimination and sentence comprehension. There were no significant changes in the intervention group on any measures of pitch discrimination after the intervention. However, the post-intervention changes on the fMRI suggest increased cortical activation in the areas associated with RAP. Additionally, significant improvement was observed for all measures of language, reading and phonological processing (except for one subtest of rapid naming). There were no significant changes on any measures taken on the control group. The authors concluded that their findings showed that Fast ForWord-Language Program was effective in remediating RAP. This seemed unrelated to attentional and motivational factors given the lack of improvement in pitch discrimination. Since Fast ForWord-Language Program was also effective in remediating reading and language difficulties in children with SRD, RAP could be considered as an important AP in reading and language.

This study provides level IIa evidence and received a methodological rating of 4/7. Its limitations in terms of methodology were a lack of blinding, reporting of effect sizes and that the paper did not report missing data management. All of these are common amongst the reviewed studies. This study has shown that the effectiveness of the Fast ForWord-Language Program in improving language and reading abilities in children with SRD was not due to repeated testing or maturation. However, the finding of the effectiveness of Fast ForWord-Language Program in improving RAP remains tentative because there was no reporting of any behavioural assessment of RAP pre- and post-intervention.

Jirsa (1992) investigated the effectiveness of an integrated ‘bottom-up’ and ‘top-down’ intervention program using an experimental design. Twenty children with APD were randomly allocated to either the intervention group or the no-intervention group. An additional no-intervention group involving 20 typically developing children was also included. The APD intervention group underwent 14 weeks of intervention that targeted auditory memory, competing noise, auditory attention, and language comprehension. Subsequently, all groups were reassessed on measures of auditory attention and dichotic listening.

Significant post-intervention improvements were noted on the left and right ear performances on the Selective Auditory Attention Competing Subtest (Cherry, 1980) and the left ear performance of the Competing Sentences Test (Willeford, 1977). At the same time, the scores of the APD no-intervention group and the typically developing group remained unchanged over the two assessment sessions. Additionally, both APD groups performed significantly more poorly than the typically developing group on the above measures before the intervention, and there were no differences between the performances of the two APD groups. The post-intervention scores of the APD intervention group were significantly higher than the APD no-intervention group providing evidence for the effectiveness of this APD intervention. This study provides level IIa evidence and received a quality rating of five out of nine. The main limitation of the study is that no specific detail of the intervention was given (e.g., references to the programs or materials used, the amount of time spent targeting each key area). Although assurances were given by the author that there were processes in place to ensure intervention that the intervention was delivered in the intended manner, description of such processes were not provided. Due to a lack of methodological details reported, it would be difficult to replicate the study.

In summary, these studies provide preliminary support for the effectiveness of the integrated top-down and bottom-up approaches to APD intervention. All six studies reported significant improvement on at least some, if not all, AP measures after training. These studies showed levels IIa and III evidence. However, four of these studies (Alonso & Schochat, 2009; Putter-Katz et al., 2008; Putter-Katz et al., 2002; Schochat et al., 2010) received only two or three points out of a possible seven or eight for their methodological quality. For most instances, there was a lack of control comparisons and the studies lacked rigour in their documentation of the protocol and the details of the intervention implemented, which make them difficult to replicate. All of the above would suggest that there is a tendency for confounds and biases not being controlled for, which would render the outcomes of these studies as tentative. Clearly, more high quality research and well-designed studies are required before more definite conclusions could be drawn regarding the effectiveness of the integrated bottom-up and top-down interventions on AP outcomes.

Gaab et al. (2007) was the only study that investigated reading and language outcomes following these interventions. The findings of this study provided promising outcomes that the intervention resulted in improved language and reading abilities. However, it is unclear whether such improvements were caused by the reading and language intervention components of the Fast ForWord-Language Program, a result of improved RAP, or a combination of the two. In order to further investigate such matters, it is imperative to isolate the effects of the bottom-up intervention and the top-down intervention. Unfortunately, the findings of the study but Gaab and colleagues do not allow further investigation into this matter. The following sections will focus on exploring the intervention-specific and generalisation effects of bottom-up and top-down approaches separately and to review the results of the studies that compared the effectiveness of the two approaches.

#### *2.2.3.2 Intervention-specific and generalisation effects of bottom-up interventions*

The literature search revealed six publications which reported a total of seven studies examining the effects of bottom-up approaches in APD intervention (see Table 2.4). In total, 111 children with APD and three children without APD participated in these studies. The interventions that were explored were: dichotic listening training, auditory spatial processing training, non-speech (frequency and RAP) and simple speech discrimination training, and modified Auditory Integration Training (AIT). Table 2.5 displays the summary of these studies.

Three studies that were reported in two publications investigated the effectiveness of dichotic listening training (English et al., 2003; Moncrieff & Wertz, 2008). English et al. (2003) investigated the effectiveness of a dichotic listening training program. Ten children suspected of APD undertook weekly dichotic listening training for 10 to 13 weeks. The authors reported improvement on dichotic listening measures following the training but did not provide the statistical evidence to support such claim. Moncrieff & Wertz (2008) reported two studies documenting the effectiveness of another dichotic listening training program. In the first study, eight children with poor left ear score on the Dichotic Digits Test (DDT) undertook that training program for 11 sessions over four weeks. There was significant pre-post intervention improvement on the left ear score of the DDT. In the second study, 13 children (10 with poor left ear scores on the DDT and three with age appropriate performance on the DDT) underwent the same dichotic listening training program for variable durations (four sessions per week for three to six weeks). There was significant improvement in both the right and the left ear DDT scores following the training. There was also improvement in listening comprehension and word recognition.

These studies provide preliminary evidence that dichotic listening skills can be improved by training. All three studies reported improvement in at least one measure of dichotic listening. Moncrieff and Wertz (2008) also reported generalisation of the training effect to listening comprehension and word recognition, but not for oral reading. However, all three studies were exploratory in nature (level of evidence = III), and received only one to two points out of seven points for the quality of the methodology. None of the studies involved a no-intervention control group[4]. Hence, the observed improvements in dichotic listening could not be clearly attributed to the training under investigation.

Cameron and Dillon (2011) reported significant improvement in auditory spatial processing ability following binaural processing training, the LiSN & Learn auditory training software (Cameron & Dillon, 2010). The LiSN & Learn software was designed to remediate auditory spatial processing disorder in children. During the training, the child is required to identify a target word in a sentence which is presented in competing speech in a three-dimensional auditory environment. Apart from the improvement in spatial processing, Cameron et al. also reported a significant improvement in measures of auditory memory and attention. This study provides level III evidence and obtained a methodological rating of 4/7. Again, the main limitation was that the study did not

[4] Three children with WNL dichotic listening abilities were included in Moncrieff and Wertz (2008), but they underwent training like the other participants in the study, and hence, were not classified as a control group.

include a control group; therefore, it is difficult to attribute any direct causal relationship between the observed gains and the intervention.

Cameron et al. (2012) subsequently published a randomised control trial to further investigate the effectiveness of the LiSN & Learn. Ten children with auditory spatial processing disorder (6;0 to 9;6 years) were randomly allocated to two experimental conditions: 1) a group who received the LiSN & Learn program, and 2) a group who undertook the Earobics program which is an educational program that mainly targeted phonological awareness (Cognitive Concepts, 2008). The researchers found that the group that underwent the LiSN & Learn program demonstrated significantly greater improvement (that was accompanied with a large effect size) in the test conditions that required spatial processing but no significant changes in performance were observed for the Earobics group. Additionally, no significant changes in performance were observed in either of the groups on the non-spatialised test conditions, which further suggest that the improvement in spatial processing of the LiSN & Learn group was specific to the LiSN & Learn program. Furthermore, there were significant improvement in the listening skills of children in the LiSN & Learn group after the intervention as shown by the rating of a parent questionnaire but there were no differences in the rating of the parent questionnaire of the Earobics group. This study provides level Ia evidence and received a methodological rating of 8/9. It provides convincing evidence that the LiSN & Learn program was effective in remediating auditory spatial processing disorder in children. It also provides support that bottom-up interventions, such as the LiSN & Learn, could result in generalisation of listening ability beyond the intervention task to everyday listening ability.

McArthur et al. (2008) investigated the effect of non-speech and simple speech (i.e., vowel discrimination and consonant vowel discrimination) training in remediating AP in children with APD and SRD/ SLI. Twenty-eight children with SRD/ SLI were found to have co-morbid difficulties in either FD, RAP, vowel discrimination (VD) and/ or consonant vowel discrimination (CVD). They underwent an adaptive, computer-based training program for their respective FD, RAP, VD and/ or CVD difficulties. The researchers found that there was significant post-intervention improvement on the respective AP ability that the children undertook training for. However, there was a lack generalisation to reading, language and spelling measures.

This study provided level IIa evidence and received a methodological rating of 5/7. The deficiency in its methodology lies in the lack of blinding, which could promote the likelihood of experimenter biases, and the lack of reporting of effect sizes. Both of these are inherent in most of the studies in the present review. Apart from these, this study provides promising evidence for the effectiveness of bottom-up interventions in remediating the specific AP difficulties that were targeted by those interventions. However, the evidence also suggests that the effects of bottom-up interventions might not generalise to other cognitive abilities such as reading, language or spelling.

Yencer (1998) investigated the effect of modified Auditory Integration Training (AIT). AIT is a 10-day training program which was developed by Dr. Guy Berard, an otolaryngologist in France. It is based on the notion that certain people have hypersensitive hearing at selected frequencies and that this can cause agitation and pain, and interferes with learning. Hypersensitive hearing is defined as the 'peaks' and 'valleys' of the audiograms where there is a 5dB or more difference in thresholds between adjacent audiometric frequencies which would result in atypical perception of sounds. AIT targets 'these distortions' by the use of altered music that have filtered out the frequencies that the individual is hypersensitive to (Berard, 1993).

Yencer investigated its effects by using an experimental design that involved an intervention group that underwent AIT, a 'placebo group', where the participants listened to unaltered music, and a no-intervention control group[5]. Although significant differences between pre- and post-intervention measures were noted in the intervention group, however, significant differences were observed in the placebo and the control group. Hence, the significant improvement in auditory function of the intervention group could not be attributed to AIT.

This study provides level IIa evidence and received a methodological rating of 5/9. The major limitation was that there was no random allocation of participants to their respective

[5] The number of participants per group was not specified in this study.

experimental groups. However, the participants were allocated based on their age and their AP ability (i.e. performance on the SSW test), which could be appropriate given the relatively small sample size and if there were vast differences in age and SSW performance in the sample. This study did no provide evidence in support of the efficacy of the AIT. ASHA's position statement has also stated that AIT has not met the scientific standards of efficacy (ASHA, 2004a).

Overall, the effectiveness of 'bottom-up' approaches to APD intervention has been investigated in only a few studies. Four of the seven studies that were published in three citations (Cameron & Dillon, 2011; English et al., 2003; Moncrieff & Black, 2008) provided level III evidence and received methodological ratings of less than four points out of the possible seven points. Again, the major limitation was that these studies did not include a control group. Hence, any observed effects might have been the result of practice, retesting, and maturation. Yencer (1998) demonstrated this point in that even the no-intervention control group showed significant improvement upon retesting. Additionally, the documentation of the protocol and details of the intervention implemented were often inadequate, which make replicating their findings difficult. However, Cameron et al. (2012) and McArthur et al. (2008) demonstrated the effectiveness of bottom-up interventions in remediating AP using experimental designs. Cameron et al. (2012) provided level Ib evidence and received a methodological rating of 8/9 and McArthur et al. (2008) provided level IIa evidence with a methodological rating of 5/7. Their findings provide promising support for the effectiveness of bottom-up interventions in remediating the AP difficulties that were targeted by those interventions.

The generalisation effect of these interventions to language and literacy ability remains largely un-investigated, with two exceptions. Moncrieff and Wertz (2008) measured language and literacy outcomes following an intervention program that used speech stimuli. They reported a significant improvement in sentence comprehension and word recognition following dichotic listening training. However, because speech stimuli were employed, e.g., digits, words, and sentences, it might be possible that the observed improvement was due to the strengthening of language-based processes rather than improved AP *per se*. McArthur et al. (2008) investigated the literacy and language outcomes following AP interventions that included non-speech and simple speech (i.e., vowel and consonant) stimuli. Presumably, the use of these stimuli would have limited the extent of language processing during the training. The researchers reported no generalisation of the AP intervention effects to literacy and language. Further research is needed to replicate these findings so that more definite conclusions could be reached regarding the generalisation effects of bottom-up interventions.

In summary, there is evidence from a high quality randomised controlled trial (RCT) and a case-control cohort study that bottom-up interventions resulted in significant intervention-specific improvement in children with APD. However, most of the other studies to date only provided weak and preliminary evidence for the effectiveness of bottom-up interventions. It is clear that more better designed experimental studies and randomised controlled trials are needed before the effectiveness of the bottom-up approaches can be clearly demonstrated. There is limited research on the generalisation of bottom-up interventions to reading and language abilities. The two studies that have explored the generalisation effects of bottom-up interventions have reported contradicting findings. More research is required to determine whether the effects of bottom-up interventions would generalise to reading and language.

#### *2.2.3.3 Intervention-specific and generalisation effects of top-down interventions*

The literature review revealed only a single case study (level of evidence = III) that explored the effectiveness of top-down interventions (Leitao, 2003) (see Table 2.6 and Table 2.7). It was surprising that only one case study was identified given that the recommendation for the use of top-down interventions is well recognised in the literature (Chermak, 1998; Chermak & Musiek, 2007). In fact, in a recent systematic review, Fey et al. (2011) did not identify any studies that investigated interventions that were solely top-down (i.e., language or literacy-based interventions, in which language or literacy contents were manipulated rather than their acoustic components).

Leitao (2003) reported a case study of a child with APD and dyslexia who underwent psycholinguistic intervention. The author reported that the child achieved age-appropriate literacy performance following the intervention. However, no empirical data were provided to support such a claim and the generalisation effect to AP was not tested. This case study fell short of many aspects of research methodology and scientific rigour (methodological rating: 0/7) that allow valid inferences to be drawn. Therefore, the effectiveness of top-down interventions for children with APD remains largely un-investigated.

#### *2.2.3.4 Studies comparing the effectiveness of bottom-up and top-down approaches*

The effectiveness of bottom-up and top-down approaches has been compared in a few studies. The literature search revealed two studies (Miller et al., 2005; Sharma et al., 2012) and one systematic review (Fey et al., 2011). Table 2.8 provides a summary of the methodologies and findings, and Table 2.9 presents an assessment of the methodological quality.

Miller et al. (2005) reported a series of seven case studies comparing outcomes for children who were suspected of APD who underwent one of three interventions: 1) a clinician-delivered auditory training program, 2) the Fast ForWord Program (Scientific Learning Corporation, 2001), or 3) Earobics interventions. The clinician-delivered auditory training program mainly targeted bottom-up AP abilities (e.g. auditory memory, auditory closure, and auditory discrimination). The Fast ForWord Program incorporates both bottom-up and top-down approaches (it uses modified speech to improve RAP and, at the same time, addresses language comprehension and phoneme discrimination). Lastly, the Earobics is a top-down language intervention program which focuses on language comprehension and phonological processing.

All children showed improvement on at least one measure of AP. However, no consistent improvement on the literacy measures was observed in any of the three interventions. Given that these are single case studies, the use of a control group was not applicable. However, single subject research can be a rigorous. There are scientific methodology that is used to establish a casual or functional relationship between the intervention and the outcome, e.g., one of key elements in demonstrating such a relationship is the use of repeated testing of the dependent variable during the difference phases of the study(e.g., at baseline, during the intervention and post intervention). This allows for the comparison of performance pattern during the different phases. The use of different study designs (e.g., the ABAB design) can also strengthen the demonstration of any potential intervention effects. However, all these methodologies were not incorporated in Miller et al. (2005) or in Leitao (2003) as discussed in the above section.

In a RCT, Sharma et al. (2012) compared the effectiveness of bottom-up and top-down approaches and the use of a frequency modulation (FM) system in schools. Fifty-five children diagnosed with APD participated. They were randomly allocated to five groups: 1) a no intervention control group; 2) a discrimination intervention group; 3) a discrimination intervention plus FM device group; 4) a language intervention group; and 5) a language intervention plus FM device group. The discrimination intervention targeted mainly bottom-up auditory processes. It comprised the discrimination training of temporal patterns, as well as top-down language-based activities for identification of syllables, segmenting word rhyming, and reading aloud. The language intervention targeted language skills such as following directions, scrambled sentences, rhythm building with musical instruments, circumlocution, building stories with pictures, summarising short stories, identifying key words in paragraphs, comprehension of sentences with different stress patterns, and reading aloud.

Sharma et al. reported mixed findings. For instance, the groups that underwent the discrimination intervention by itself, and the language intervention by itself, showed significant improvement on the Frequency Pattern Test, whereas the groups that underwent the discrimination intervention and the language intervention with FM did not show such an improvement. Similarly, three of the intervention groups (the discrimination intervention group, the discrimination intervention with FM group, and the language intervention group) showed significant improvement in the overall language measure (the CELF-4), whereas the Language plus FM group did not.

One explanation put forward by these authors for these results is that the study had low statistical power. Like other studies (e.g., Putter-Katz et al. (2002), English et al. (2003), and Deppeler et al. (2004)), the sample size in each group was small, ranging from five to ten participants per group. Sharma and colleagues reported one generalisation effect from discrimination training to language ability, with a significant improvement in the Core Language Score of the Clinical Evaluation of Language Fundamentals - Fourth Edition (CELF-4) (Semel, Wiig, & Secord, 2003) in both groups that underwent discrimination training. However, language was also a substantial part of the discrimination training. For instance, speech stimuli of phonemes, syllables, and words were used as stimuli, and read aloud was part of the training. The improvement of language ability might have been due to the strengthening of language processing because of repeated exposure to the speech and language stimuli, rather than a generalisation effect of improved auditory discrimination *per se*. Generalisation effect from discrimination training to language would have been more clearly demonstrated if only non-speech stimuli were used during the training.

Finally, Fey et al. (2011) conducted a systematic review of peer-reviewed journals[6]. The search terms were: ‘auditory processing disorder’ or ‘auditory perceptual disorder’ combined with ‘intervention’, ‘management’, and ‘training’. They searched 28 databases and evaluated the peer-reviewed literature from 1978 to 2008 on the efficacy of auditory training and language intervention for children with APD and SLI. However, studies with participants who had a primary diagnosis of SRD or learning disability but without an accompanying APD or SLI, and those where the participants had autism spectrum disorder, hearing loss, or cognitive disability were excluded.

Only studies written in English that contained original data were considered. The other inclusion criteria were that the studies were to have involved school-age children (6 to 12 years old) diagnosed with APD and/or SLI, and that the intervention used were direct interventions designed to influence children's ability to process speech and language. The studies that used indirect

[6] The present systematic search of the literature had also identified another systematic review (Loo et al., 2010). However, this study was excluded from the present review because it did not specifically sample for studies that concerned children with APD but targeted studies that investigated interventions for SRD and SLI.

management approaches that were designed to compensate for children's AP difficulties, such as classroom modification, preferential seating and FM system, and those that used mixed management approaches were also excluded.

Fey and colleagues identified 192 citations for which 23 studies met the selection criteria. However, only six studies involved children with APD (Deppeler et al., 2004; English et al., 2003; Jirsa, 1992; Miller et al., 2005; Putter-Katz et al., 2002; Yencer, 1998). All of these studies have also been included in the current review, except Deppeler et al. (2004) which did not meet the present selection criteria because the original study did not specify that their participants were children with APD or suspected APD, rather that they satisfied the criteria set by the Scientific Learning Corporation (SLC) for the use of the Fast ForWord Program[7] (p. 97). The family of the potential participants was given details of the Fast ForWord–Language and the details of the study through an audiologist and a number of speech pathologists. Those who were interested and met the criteria listed in Footnote 7 were recruited. Pre-training AP ability was measured by the SSW and the AB Words in Speech Spectrum Noise, however, details of those results were not published and it remains unclear whether the participants presented atypical results on those tests prior to the training.

Fey and colleagues concluded that there was only weak evidence suggesting that intensive, short-term interventions (which included both bottom-up and top-down interventions) may be associated with improved auditory function in children with APD. There was also little evidence suggesting that these interventions also have a generalisation effect on language abilities. Most studies were exploratory in nature and did not involve a control group. Fey and colleagues commented that more high-quality, larger, well-controlled, hypothesis-driven experimental trials are needed to investigate the efficacy of auditory and language intervention in this population.

[7] These criteria include: “full-scale IQs above 80; average or above nonverbal intelligence; hearing acuity and middle ear function within normal limits; and no previous diagnoses of ADHD, autism, neurological disorders, intellectual disabilities, or emotional disorders. No child received intervention additional to FFW during the initial three phases of this study” (Deppeler et al., 2004) (p. 97).

### 2.2.4 Conclusion

In summary, there is preliminary evidence that interventions which involve both bottom-up and top-down approaches are effective in remediating AP deficits in children with APD. However, many of these studies were exploratory in nature and hence, their conclusion of the effectiveness of those interventions remains only tentative.

Some promising evidence has emerged from two experimental studies regarding the intervention-specific effects of bottom-up interventions for children with APD (Cameron et al., 2012; McArthur et al., 2008). More of such studies are required to demonstrate the effectiveness of other bottom-up interventions. There is limited research on the generalisation effects of bottom-up interventions to other cognitive abilities, such as reading and language. The two studies that investigated the matter showed contradicting results (McArthur et al., 2008; Moncrieff & Wertz, 2008).

Despite the widely accepted recommendation that direct APD intervention should include top-down interventions, only one case study had been identified by the present systematic review, which explored the use of psycholinguistic interventions for a child with APD (Leitao, 2003). The author reported significant improvement in literacy after the intervention, but did not provide the empirical evidence in support of such changes. Miller et al. (2005) included case studies regarding the effectiveness of the Earobics program for two children with APD in a series of case studies comparing the effectiveness of top-down and bottom-up interventions. Like Leito (2003), these case studies lacked experimental rigour (e.g., of repeated measurement across the different phases of the study, or the use of ABAB design to demonstrate the effect of the intervention on the dependent variable) that allows valid inferences regarding the effectiveness of the interventions to be drawn. Additionally, the transference of the top-down intervention effect to AP ability was not explored in either study. The effectiveness of top-down interventions for children with APD remains largely un-investigated.

The effectiveness of top-down and bottom-up interventions has been compared in two other citations: in a RCT (Sharma et al., 2012), and in a systematic review (Fey et al., 2011). For example, the conclusion from the systematic review of Fey et al. was that there was no compelling evidence that the auditory interventions investigated by the studies reviewed showed any significant effects on auditory, language and academic outcomes of school-age children diagnosed with APD. Again, the studies reviewed by Fey et al. had been exploratory in nature, and therefore, there is a need for more high-quality, experimental trials to determine the effectiveness of bottom-up and top-down approaches to APD before more definitive conclusions can be drawn.

The studies reported in Chapters 3 and 5 of the current thesis aimed to investigate and compare the effectiveness of bottom-up, top-down, and combined bottom-up and top-down approaches in APD intervention and their generalisation effects. This research is conducted in the context of a particular type of AP deficit, namely, auditory frequency discrimination (FD) difficulty. FD difficulty was chosen because it is the most widely affirmed AP deficit that has been linked to poor reading ability (see Farmer & Klein, 1995, for review). Studies have repeatedly demonstrated that FD is associated with language and reading abilities, in that children with language and reading difficulties often demonstrate difficulty with FD as well (Halliday & Bishop, 2006; Hill et al., 2005; McArthur & Bishop, 2004; Mengler et al., 2005). Additionally, the testing and training of FD can be conducted using non-speech stimuli. Therefore, the effects of an AP intervention could be measured separately from speech and language processing mechanism. This was crucial in exploring the separate effects of bottom-up and top-down interventions. This would also allow for the investigation of the generalisation effect of bottom-up intervention to language and literacy abilities.

Very limited research has investigated the nature of FD in children with APD at the time of the current thesis. However, FD has been the focus of research in SRD and SLI for decades. The next section of this thesis will provide a review of this literature and the literature concerning the training of FD ability.

## 2.3 Frequency discrimination – An important auditory process associated with reading and language

Interest in FD ability in children with SLI and SRD stems partly from early evidence that a perceptual deficit concerning RAP might underlie SLI (Tallal & Piercy, 1973a, 1973b, 1974, 1975). These researchers found that children with SLI had significant difficulty with a task involving temporal order judgement (TOJ) of brief and/or rapidly changing stimuli (e.g., tones, vowels, or syllables with short formant transitions or inter-stimuli intervals - ISIs).

The task typically involved the presentation of two stimuli sequences, e.g., different patterns of high and low tones (i.e., high-high, low-high, high-low, and low-low), or vowels and syllables. The children were required to push the panels on a response box that corresponded to the pattern of presentation of the stimuli. Tallal and Percy found that children with SLI performed significantly more poorly (i.e., less accurately) than the controls when the stimuli used were brief or when the ISIs were short (shorter than 305ms). However, these difficulties were not observed for stimuli with extended formant transitions or those that were presented at long ISIs. It was concluded that the children with SLI showed a deficit of RAP and that there was a causal relationship between a RAP deficit and SLI. These findings were extended to children with SRD in a follow-up study (Tallal, 1980).

Since then the causal relationship between a RAP deficit and SRD/SLI has been the subject of research and debate. Inconsistent findings have been reported. A number of studies have provided evidence in support of this proposition (Reed, 1989; Tallal, 1980; Tallal & Piercy, 1973a, 1973b, 1974, 1975; Wright et al., 1997); also see (Farmer & Klein, 1995) for a review. However, other studies have failed to find RAP deficits in SRD (Amitay, Ahissar, & Nelken, 2002; Mody, Studdert-Kennedy, & Brady, 1997; Nittrouer, 1999) or in SLI (Bishop, Carlyon, Deeks, & Bishop, 1999). Additionally, other studies have found that children with SRD/SLI had difficulty discriminating tones regardless of the speed of presentation (Ahissar et al., 2000; Baldeweg et al., 1999; Bishop, Bishop, et al., 1999; Bretherton & Holmes, 2003; France et al., 2002; Hari, Sääskilahti, Helenius, & Uutela, 1999; McAnally & Stein, 1996; Nittrouer, 1999; Share, Jorm, MacLean, & Matthews, 2002).

It has been suggested that one possible explanation for the inconsistent findings in the studies of RAP could be that poor performance on RAP tasks is a result of another deficit, rather than of RAP. One possible deficit could be FD, which became apparent in a paradigm that stressed FD by imposing time constraints (McArthur & Bishop, 2001, 2004; Reed, 1989). McArthur and Bishop (2004) argued that the task used to assess RAP, the TOJ task (Tallal & Piercy, 1973a, 1973b, 1974, 1975), along with other tests of RAP, all relied on FD. The TOJ task required the participant to recreate the order of pairs of high and low tones (i.e., high-high, high-low, low-high, and low-low) using appropriate key presses. The ISI was manipulated to determine the rate of stimulus presentation, so that short ISIs (i.e., when the tones were presented more rapidly) would further stressed the ability to discriminate between the frequencies. Very few studies have controlled for differences in auditory discrimination ability between participants while measuring their rapid temporal processing ability (McArthur & Bishop, 2001).

Since then, several studies have found that many individuals with SRD/SLI show impaired FD. For example, with respect to SLI, Mengler et al. (2005), McArthur and Bishop (2004) and Hill et al. (2005) all found significantly poorer FD in children with SLI compared to matched controls. These significant differences were noted regardless of stimuli duration (McArthur & Bishop, 2004) and were found to be stable over time (Hill et al., 2005). No significant differences were observed for backward masking (Hill et al., 2005) or gap detection in broadband noise (McAnally & Stein, 1996), which are measures of temporal processing that are independent of FD.

Regarding FD and reading, De Weirdt (1988) found that poor readers were significantly worse than a group of ‘good readers’ at identifying whether pairs of pure tones (130 ms in duration) sounded the same or different. Baldeweg et al. (1999) found significant differences in the mismatch negativity (MMN) potentials[8] between a SRD group and a control group when they were presented

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[8] MMN is an attention independent auditory event-related potential that is elicited in response to infrequent deviant auditory stimuli embedded in an unattended sequence of frequent standard stimuli. The cortical generators of MMN

with changes in tone frequency, but no difference when presented with differences in tone duration. Additionally, they found a significant correlation between FD ability and the reading of regular words, and non-words. Additional findings of poor FD in the SRD population have been reported in other studies, e.g., in McAnally and Stein (1996), and Halliday and Bishop (2006).

Many studies have investigated the relationship between FD and reading in unselected cohorts of individuals. Ahissar et al. (2000) investigated the relationship between AP, literacy, and other cognitive abilities. One hundred and two adults (aged 16-58 years) were recruited from the general population with different degrees of reading abilities. They found that RAP tasks that were dependent on FD, like Tallal’s original task, were significantly correlated with word and non-word reading ability. However, RAP tasks that were independent of FD, e.g., tone detection with varying ISI and backward masking, did not correlate significantly with reading performance. Talcott et al. (2002) also examined similar correlations with FD in 350 randomly selected primary school children. They found a significant relationship between FD and reading ability, even after controlling for age and IQ. Lastly, in the field of music training, Tsang and Conrad (2011) examined whether music processing skills predicted the reading performance of 69 children, aged 5 to 9 years, with and without formal music training. They found that children with formal music training showed significantly better pitch discrimination skills than children who had not received such training. Additionally, pitch discrimination ability significantly correlated with phonological awareness and word identification ability in children without formal music training. Similar findings were reported in other studies (Anvari, Trainor, Woodside, & Levy, 2002; Barwick, Valentine, West, & Wilding, 1989; Douglas & Willatts, 1994; Lamb & Gregory, 1993; Peynircioğlu, Durgunoğlu, & Oney-Kusefoğlu, 2002).

In summary, in recent years, FD has emerged as an important AP ability that has been repeatedly demonstrated to be associated with reading and language abilities. The interrelationship between FD (or other AP abilities), SRD and SLI is poorly understood. The studies presented in

have been located bilaterally to the vicinity of the auditory cortex (Csepe, 1995; Scherg, Vajsar, & Picton, 1989). Previous studies have shown a close correlation between behavioural performance and MMN in healthy subjects with normal hearing (Lang, Nyrke, & Ek, 1990) and children with SLI (Korpilahti & Lang, 1994).

Chapter 3 and 5 of the present thesis aimed to investigate this interrelationship. The remainder of this literature review will focus on presenting the current state of knowledge about FD, SRD and SLI, including the prevalence of FD in individuals with SRD and SLI, the research concerning the neurophysiological mechanisms which are thought to contribute to poor FD in individuals with SRD and SLI, and the intervention studies that investigated the effectiveness of FD intervention in individuals with SRD and SLI.

### 2.3.1 Prevalence of frequency discrimination difficulties in SRD and SLI

It is now recognised that AP deficits, including poor FD, exist in subgroups of individuals with SRD/SLI. According to Moore (2012), these deficits occur in 30% to 50% of children with SLI and SRD. McArthur et al. (2008) investigated auditory processing deficits in children with SRD and SLI. Sixty-five children with SRD, 25 with SLI, and 35 controls participated in the study. The AP skills that were assessed included: FD, RAP, vowel discrimination, and consonant-vowel syllable discrimination. They reported that 42% of their SRD/SLI sample showed an abnormal FD threshold for their age. Smaller percentages of children experienced other types of AP deficits; for example, 12% showed a RAP deficit, 23% showed poor vowel discrimination, and/or showed difficulty discriminating consonant-vowel syllables. Similar percentages of FD deficits have been reported in other studies, e.g., Amitay et al. (2002) found that 48% of their participants with SRD showed a FD deficit. The causes for poor FD remain unclear. However, it has been proposed that poorer FD may be indicative of poorer neurophysiological functioning, which will be addressed in the next section.

### 2.3.2 Neurophysiological mechanisms contributing to poor FD in SRD/SLI

#### *2.3.2.1 FD and neural phase locking.*

A few neurophysiological hypotheses have been proposed regarding the mechanisms that might underlie poor FD performance in SRD/SLI. One hypothesis suggests that FD deficit maybe a result of impaired neuronal phase locking (McAnally & Stein, 1996). The perception of pitch is thought to be dependent upon both spectral and temporal information. Low frequencies (1k Hz to 4 kHz) are processed based on temporal information, i.e., via phase-locking, that is, the auditory nerves fire in synchrony with the peak of each cycle of the auditory waveform such that a higher rate of phase-locking corresponds to a higher frequency. This is despite the fact that spectral information is still available at these frequencies. However, for frequencies above 4 to 5 kHz, pitch perception is accomplished through tonotopic representation via spectral analysis in the cochlea, i.e., different frequencies of the sound excite different sections of the basilar membrane (Moore, 1973; Moore & Sek, 1995; Plack & Carlyon, 1995)

McAnally and Stein (1996) proposed that poor FD might be the result of impaired phase locking which affects the individual's ability to extract information from the fine acoustic structure of auditory stimuli. McAnally compared the performance of 23 adults with dyslexia and 26 matched controls on four auditory tasks: 1) gap detection in broadband noise; 2) pure tone FD around 1 kHz; 3) detection of a 1 kHz tone presented in a dichotic noise masker when the tone was in phase at the two ears (N0S0); and 4) when the phase of the tone was inverted in one ear, i.e., the tone was presented in opposite phases between the two ears against the dichotic masker (N0Sπ). They found that there were no significant differences between the two groups for gap detection and for the N0S0 condition. However, there were significant group differences in the FD and the N0Sπ conditions.

Binaural detection of a low frequency tone in background noise depends upon the interaural phase of the sound wave of both the tone and noise. The difference in the interaural phase of the noise and the tone typically makes detection of the tone easier. However, the benefit of phase differences was not observed in the group with dyslexia. Therefore, the authors also proposed that individuals with dyslexia might be impaired in generating phase locked neural discharges, in decoding them in the auditory brainstem, or in analysing and interpreting them in the higher auditory cortex. This might have reduced their ability to exploit differences in the interaural phase of the tone and the noise.

However, the phase locking deficit in SRD remains controversial. Hari et al. (1999) compared the performance of 13 individuals with dyslexia and 20 typical reading controls on FD tasks involving two types of stimuli: 1) sinusoidal (pure) tones of approximately 1 kHz; and 2) burst of amplitude-modulated (AM) white noise at approximately 80Hz. Both tasks rely on pitch perception. However, the differences between the two types of stimuli were that one contained spectral information, i.e., the sinusoidal tones, but the other was a periodicity pitch in which spectral cues were absent. Hari et al. hypothesised that if a phase locking deficit in dyslexia was present, then the group with dyslexia should be relatively **more impaired** in discriminating periodicity pitch than spectral pitch.

The results showed that children with dyslexia showed significantly poorer thresholds on both tasks compared to the controls. Additionally, both groups showed higher thresholds for periodicity pitch than for spectral pitch, i.e., a larger frequency difference was required in both groups to differentiate the periodicity pitch. Moreover, the children with dyslexia showed significantly less difficulty than controls in discriminating periodicity pitch than spectral pitch. This was contrary to the researchers' assumption. Therefore, Hari et al. concluded that a deficit in phase locking was not sufficient when explaining the auditory processing difficulties of the dyslexia group.

The above conclusion seems contentious. Firstly, Hari et al. mentioned that the analysis of pitch around 1 kHz occurred "in the cochlea mainly on the basis of place coding" (Hari et al., 1999 pp. 2347). However, based on earlier research (Moore, 1973; Moore & Sek, 1994, 1995; Plack & Carlyon, 1995; Saberi & Hafter, 1995; Sek & Moore, 1995; Srulovicz & Goldstein, 1983), it is widely accepted that the frequency encoding of sounds below 4 kHz is based on phase locking. Hence, phase locking would have been involved in the spectral pitch task as well as the task involving the periodicity pitch. Therefore, the finding that the SRD group performed significantly more poorly than controls on both the discrimination of spectral and periodicity pitch was in fact evidence in support of the phase locking hypothesis. Further understanding of the differences in processing the two types of pitches would aid with understanding the rationale behind this hypothesis and might also provide a possible explanation for the obtained results.

In another study, Hill, Griffiths, Bailey, and Snowling (1999) tested the phase locking hypothesis by comparing the FD ability at 1 kHz and 6 kHz in 12 individuals with SRD and matched controls. Drawing from the notion that phase-locking occurs for frequencies below 4 kHz, they hypothesised that if the SRD group had impaired phase locking, then they would perform significantly poorer than the control for FD at 1 kHz but not for 6 kHz. However, they found that the SRD group had unimpaired FD at either frequency.

The results of this study not only contradict the phase locking hypothesis but also the many studies that have demonstrated an FD deficit in SRD. France et al. (2002) suggested that a difference in methodology in the task paradigm might be a possible explanation for this non-significant finding. Different task paradigms have been employed in studies investigating FD. Most studies have used the two-interval, same-different (2I_AX) paradigm (i.e., the task involves two tones being presented and the participant being asked to identify whether the two are the same or different), for example, in Thompson, Cranford, and Hoyer (1999) and France et al. (2002). The three-interval, two alternative force-choice (3I_AXB) paradigm has been used in more recent studies (e.g., Halliday & Bishop, 2006; Halliday, Taylor, Edmondson-Jones, & Moore, 2008; McArthur et al., 2008; Moore, Ferguson, Halliday, & Riley, 2008). In this paradigm, three tones are presented successively, two standard tones and a variable target tone. The target tone is randomly allocated to either the first or the third interval and the participant is asked to identify the target tone. However, Hill et al. used a four-interval force choice paradigm where four tones were presented, three standard tones and a target tone. The standard tones were presented routinely in the first and fourth intervals of each trial and the target tone and the remaining standard tone were varied randomly between the second or the third interval. Once again, each participant was asked to identify the target tone. France proposed that this repeated exposure to the standard tone of three times per trial could have helped to compensate for an auditory memory deficit which might be present in individuals with SRD. Hence, this resulted in improved FD for the SRD group.

In summary, whether FD deficit results from impaired neuronal phase locking remains unclear. There is preliminary evidence in support of this hypothesis, and the studies that demonstrated otherwise were confounded by methodological limitations. More research in this area is needed to replicate the results of earlier studies for a consensus to be established.

#### *2.3.2.2 FD and short-term memory*

The idea that FD deficit in SRD is associated with a memory deficit was suggested by Ahissar (2007) and Ahissar, Lubin, Putter-Katz, and Banai (2006). Ahissar et al. proposed that individuals with SRD might have a deficiency in storing, and subsequently accessing, stimulus-specific short-term memory representations. They termed this the perceptual anchors hypothesis. Ahissar et al. (2006) conducted a study comparing the performance on two FD tasks with different conditions: 1) the standard condition, where the standard tone had a fixed frequency across trials; and 2) the non-standard condition, where the standard tone had variable frequency across trials. Previous research has shown that discrimination thresholds were lower when one of the two stimuli was invariant than when both were varied (Harris, 1948). However, Ahissar et al. (2006) observed that their group of teenagers with SRD and a co-morbid learning difficulty (SRD + LD) did not display this pattern. Their discrimination thresholds were significantly higher (poorer) than the controls in the non-standard condition, i.e., the one where the standard tone had variable frequency across trials. Also, while the thresholds of the control group were reduced in the standard condition, the discrimination thresholds of SRD + LD group were found to be higher in the standard condition. Overall, these results demonstrated that the SRD + LD group did not seem to benefit from the reference stimulus, which was interpreted as indicating a deficit in memory and retrieval. These findings and conclusions were later extended to the SRD population in general (Banai & Ahissar, 2004, 2010).

However, like the phase locking hypothesis, there is no universal acceptance that a deficit in forming a perceptual anchor underlies poor FD in SRD. Wijnen, Kappers, Vlutters, and Winkel (2012) tested the perceptual anchor hypothesis by replicating Ahissar et al. (2006) study in individuals with SRD without learning difficulty. They reasoned that if the perceptual anchor hypothesis was valid, then the same findings should be observed in individuals with ‘pure’ SRD. A group of 25 adults with SRD and 29 controls matched for age and education level participated in the study. Wijnen et al. (2012) employed the same experimental paradigm as the one used in the original research. FD was assessed in these two groups using the two experimental conditions. The results showed that both groups yielded a significantly lower (i.e., better) discrimination threshold in the standard condition compared to the non-standard condition. Therefore, both groups seemed to have benefited equally from the presence of an invariant stimulus and the SRD group did not show a deficit in perceptual anchoring. Therefore, evidence in favour of the hypothesis that FD deficit in SRD stems from a short-term memory deficit is inconclusive. Further research is needed to clarify the relationship between short-term memory and FD, and to explore the possible reasons underlying the inconsistency in research findings.

#### *2.3.2.3 FD and attention*

Earlier studies on the influence of attention on psychoacoustic tasks conducted by Breier and colleagues (Breier, Fletcher, Foorman, Klaas, & Gray, 2003; Breier et al., 2001; Breier, Gray, Fletcher, Foorman, & Klaas, 2002), compared the performance of children with SRD, with and without comorbid ADHD (Attention Deficit Hyperactivity Disorder), on a range of psychoacoustic tasks including TOJ, temporal discrimination, and syllable discrimination. They proposed that the association between SLI/SRD and poor AP could be an artefact, in that the elevated (poor) threshold scores on these psychoacoustic tasks might be a result of fluctuating attention rather than a genuine inability to hear differences between sounds.

This idea was taken up by Sutcliffe, Bishop, Houghton, and Taylor (2006) who set out to examine the role of attention in the context of FD. Sutcliffe and colleagues compared FD performance of children with ADHD who had no other co-morbid learning difficulties, on and off stimulant medication, with matched controls. Eighteen children with ADHD and 18 age-matched children without ADHD participated in the study. Children without ADHD were assessed twice, and the children with ADHD were assessed once on stimulant medication and once off medication. Sutcliffe et al. found that the FD performance in children with ADHD was significantly better with stimulant medication than without the medication. Without the medication, their performance was more variable and tended to deteriorate with repeated trials on the same task. Additionally, children with ADHD were significantly poorer in FD than the children without ADHD when the former were off stimulant medication. Yet, when they were on stimulant medication, FD performance of children with ADHD converged with that of the control children. Therefore, Sutcliffe et al. concluded that attention may influence performance on FD tasks, and suggested the need for controlling for attention ability when investigating the FD performance of children with SRD/SLI.

The effect of attention on FD was also investigated by Moore et al. (2008). These researchers tested FD thresholds and response variability in 20 children (6 to 11 year-olds) recruited from local schools, and a comparison group of 21 adults (age not specified). They identified three profiles of response patterns in the FD task. The first profile: the ‘good performers’, who produced consistent responses at low (adult-like) threshold levels. The second profile: the ‘genuine poor performers’, who produced consistently elevated (i.e., poor) thresholds. Yet, the majority of children demonstrated a third profile. They were referred to as the ‘non-compliant responders’ who often performed quite accurately and consistently during the first few trials of the task but not during subsequent trials. Success on the first few trials suggests that they were able to do the task and to discriminate between the stimuli. However, their performance declined on subsequent trials, often after they had made an error and subsequently started to make incorrect discriminations even on the stimuli that they had previously performed accurately. Their performance also varied considerably between each run of the task, when they were tested on the same task multiple times (i.e., multiple ‘runs’). The researchers proposed that this pattern of performance could be attributed to fluctuating attention. The finding that these children demonstrated appropriate discrimination typically during the initial stages of the task provides strong support for this hypothesis.

Moore, Ferguson, Edmondson-Jones, Ratib, and Riley (2010) conducted a larger study to investigate poor FD and APD in an unselected cohort of children. One thousand, four hundred and sixty-nine (1,469) children were randomly selected from local schools. The children were tested on a battery of AP tasks: 1) FD; 2) backward masking with a zero-millisecond gap (BM0); 3) backward masking with a 50-millisecond gap (BM50); 4) simultaneous masking where the tone was presented in continuous noise (SM); 5) simultaneous masking with spectral notch (SMN) where the target stimulus had a tone that was presented within a quiet spectral notch; and 6) a speech-in-noise test involving vowel-consonant-vowel syllables. Additionally, the children were tested on a range of cognitive tests: IQ, memory, language and literacy, and attention (auditory and visual) measures. Two sensory scores were derived based on the performance of the BM0 and BM50, and SM and SMN tasks, namely a score for temporal resolution (TR) and a score for frequency resolution (FR). They were derived by subtracting the BM50 threshold from the BM0 threshold, and the SMN threshold from the SM threshold respectively. The BM50 task and the SMN task acted as ‘control’ tasks for the BM0 task and the SM task. By means of this subtraction, the researchers aimed to eliminate any non-sensory related factors (e.g., memory or other factors related to task demands) that might have influenced the BM0 and SM threshold scores. Intrinsic attention was also measured through derived ‘variability’ scores for the individual AP task, while extrinsic attention was measured by the reaction times to cued and un-cued stimuli.

The findings showed that poor AP ability was generally related to inattention rather than a deficit in sensory processing. The majority (~95%) of children who performed poorly on individual AP tests were **not** found to be poor performers based on the derived sensory scores. These children performed poorly even on the control tasks of BM50 and SMN, and showed general difficulty with the task demands. Additionally, these children tended to achieve significantly lower scores on the cognitive tests compared to the children with typical AP ability. The former also showed significantly greater performance variability (across the different AP tests and across different trials of the same test) than did the typical performers. Therefore, the researchers proposed that this variability was a result of inattention which had affected performance on AP tasks and the other cognitive measures. They suggested that attention is an important factor affecting performance on AP tasks in most children with poor AP abilities.

A potential limitation of this study is that it does not provide direct evidence for the role of attention on the FD task per se. The derived score of FR was based on frequency **detection** in simultaneous masking (i.e., the detection of the target interval that contains a tone versus the standard intervals that did not contain the tone), which could arguably be different from FD which involves comparing the tones for spectral differences. Unlike the BM0 and the SM tasks that were paired with the BM50 and the SMN tasks as control tasks, performance on the FD task was not compared with a task that was parallel to it in terms of its task demand. Therefore, the effect of attention on FD performance was not directly tested.

In summary, there is evidence suggesting that performance on FD tasks can be affected by attention. Further research is needed to explore whether attention has an effect on psychoacoustic tasks in general or whether it is specific to FD. The use of control tasks like the BM0 and SM tasks used in Moore et al. (2010) seems promising and could be applied to FD. The specifics of what such control tasks might entail remains to be determined. For instance, a possible control FD task could be a task that involves large frequency differences between the target stimuli and the standard tone which children could discriminate with ease. Threshold detection would not be the focus of such a task; instead, the task would give an indication of the variability in response adjustment. The variability in response adjustment between the control FD task and the standard FD could be compared. This could be an indication of how well children could engage and sustain their attention during psychoacoustic FD tasks.

#### *2.3.2.4 FD, neuro-maturation and intelligence*

It is widely accepted that neuro-maturation contributes to the performance on FD tasks even in typically developing individuals. Firstly, a number of authors have reported that typically developing children, who were younger than six years, had difficulty understanding the task demands of FD tasks (Halliday et al., 2008; Moore, Cowan, Riley, Edmondson-Jones, & Ferguson, 2011; Moore et al., 2008; Thompson et al., 1999). For instance, Thompson et al. (1999) compared FD ability in typically developing children of different age groups to the FD ability in adults. Sixteen 5 year olds, ten 7 year-olds, ten 9 year-olds, and ten 11 year-olds participated in the study. Their performance was compared to a group of ten adults (aged 22 to 41 years, mean = 28.6 years, SD was not reported). The researchers found that the majority of 5 year olds could not learn and do the experimental task. However, all children in the three older age groups and the adults were able to successfully complete the task.

Halliday et al. (2008) tested the FD ability in 70 children aged 6 to 11 years recruited from local schools. They found that, in general, younger children (the 6 to 7 years olds) performed more poorly and showed greater variability in FD performance, even after training. Additionally, there were a number of children, mainly in the 6 to 7 year age group, who had to be excluded from the study because they could not discriminate between the stimuli, even those with the largest frequency difference.

Moore et al. (2011) also found that performance on AP measures generally showed lower thresholds and reduced variability with increased age. They observed that children aged 6 to 7 years performed significantly more poorly than children in the older age groups. Additionally, 35% of the younger group could not master the FD task. Other studies have also reported that FD appears to present difficulties for young children (Cowan et al., 2005; Jensen & Neff, 1993; Moore et al., 2010; Sutcliffe & Bishop, 2005).

Finally, there are still other factors that have been reported to contribute FD performance, such as non-verbal intelligence (Amitay et al., 2002; Amitay, Halliday, Taylor, Sohoglu, & Moore, 2010; Amitay, Hawkey, & Moore, 2005 ; Deary, 1994; Halliday et al., 2008; Talcott et al., 2002) and motivation (Amitay et al., 2010). For instance, Amitay et al. (2002) compared performance across a battery of AP tasks, and reading and intelligence tests in 23 individuals with SRD and 26 controls. They found that some participants with SRD demonstrated FD threshold scores that were compatible with those in the control group, while others showed poorer FD than the controls. The SRD group with poor FD also showed significantly poorer non-verbal intelligence than the group with SRD but typical FD, even though the two SRD groups did not differ in their reading abilities. In another study, Halliday et al. (2008) found that some typically developing children were able to achieve adult-like FD performance without any training. These children tended to have higher than average non-verbal intelligence and were older. The association between maturation and intelligence has also been reported in other studies (e.g. Amitay et al., 2005 ; Deary, 1994; Halliday et al., 2008; Talcott et al., 2002).

In summary, there is a large body of research investigating the relationship of AP deficits in children with SRD and/or SLI. FD deficit has been repeatedly found to be the most common AP deficit in children with SRD/SLI. Some studies have investigated the factors that contribute to poor FD performance in children. A number of hypotheses have been proposed, e.g., poor phase locking, memory, attention, maturation, and intelligence. FD difficulty has been explored in children with SRD, SLI-children, and typically developing children. However, there is only limited research exploring FD difficulty in children diagnosed with APD.

Therefore, the first study in this thesis (STUDY 1) aims to investigate whether children with APD who were found to have poor FD, differ in terms of their language ability, phonological processing ability, word reading ability, auditory sustained attention, and executive control, from children with APD who do not show poor FD (see Section 3.1 for the specific research question). The second study of the thesis (STUDY 2) is concerned with the training of FD and whether this enhances the effect of reading training in children with FD and reading difficulties (see Section 5.2

for the specific research questions). The following section is a review of the literature pertaining to the effect of FD training.

## 2.4 FD Learning and Intervention

The suggestion that training AP abilities to improve cognitive abilities, such as language and reading, originated from the work of Tallal and Merzenich. Tallal et al. (1996) and Merzenich et al. (1996) published two influential studies that investigated the use of acoustically-modified speech to remediate RAP deficits in SLI. In the first study, seven children with SLI, aged 5 to 9 years, undertook a language intervention program using speech that was acoustically modified to aid RAP. After training, significant improvements were demonstrated for RAP as measured by the TOJ task, and also for speech discrimination and language comprehension.

A second study was conducted with a larger group of children with SLI. Twenty-two children, aged 5 to 10 years, participated in this study. The children were divided into two matched groups according to non-verbal intelligence and receptive language abilities. Children in both groups underwent language intervention. One group underwent an intervention with natural speech while the other underwent an intervention with modified speech. Following intervention, both groups improved significantly on all three measures. However, those in the modified speech group showed significantly greater improvement than the other group on measures of TOJ, speech discrimination, and sentence comprehension. The authors concluded that the training remediated the underlying RAP deficit which contributed to the difficulty with speech perception and language comprehension, and this enhanced the outcome of the language intervention. This led to the design of a computerised intervention program, the Fast ForWord Program. Due to the earlier claims that children with SRD might also demonstrated RAP deficit (Tallal, 1980), the Fast ForWord Program had been advocated as intervention for SRD as well. However, the evidence to date suggests that the Fast ForWord Program is not any more effective that other language or reading interventions that do not involve modified speech (Gillam et al., 1995, Given et al., 2008). A detailed discussion relating to the research about the effectiveness of the Fast ForWord Program goes beyond the scope of this thesis (see Loo et al. (2010) and Fey et al. (2011) for systematic reviews and discussion). Since then, there has been interest in the use of auditory training to remediate SRD and SLI. Research has focused on investigating the association between FD, literacy, and language abilities, with a focus on the effects that FD training might have on FD performance, literacy, and language abilities (Halliday et al., 2008; Halliday, Taylor, Millward, & Moore, 2012; McArthur et al., 2008; Millward, Hall, Ferguson, & Moore, 2011; Moore et al., 2008; Moreno & Besson, 2005; Sutcliffe, 2006). The findings of these studies will be discussed in the next section, which will focus on two main issues: 1) the effect of FD training on FD ability; and 2) the generalisation effect of FD training to language and reading abilities.

### 2.4.1 The effect of FD training on FD performance

There is ample evidence demonstrating that FD ability can be improved by training in adults recruited from the general population. This has been demonstrated behaviourally on psychoacoustic FD tasks, as well as neuro-physiologically, on measures such as the auditory ERPs. For instance, Halliday, Moore, Taylor, and Amitay (2011) compared the outcome of FD training and intensity training in normal hearing adults recruited from the general population. Sixty-four adults were divided into three groups matched according to their pre-training FD ability. Group one (n = 19) underwent FD training, Group 2 (n = 20) underwent intensity training, and Group 3 was the control group who did not undergo any training. All the groups, including the control group, improved their intensity discrimination threshold scores. However, only the group that undertook the FD training showed a significant improvement in FD ability. A similar finding has been observed in other studies (e.g., Demany & Semal, 2002; Irvine, Martin, Klimkeit, & Smith, 2000; Micheyl, Delhommeau, Perrot, & Oxenham, 2006; Tong, Melara, & Rao, 2009 ).

More strikingly, FD can be improved through training that utilised identical stimuli which, by definition, were impossible to discriminate correctly beyond “chance probability” (Amitay, Irwin, & Moore, 2006, pp. 1617). Amitay et al. (2006) assessed FD in 10 groups of 12 adults (i.e., 120 participants in total) with normal peripheral hearing who were recruited from the general population. There were nine training groups and one control group. The training groups differed in terms of the training paradigm and the stimuli used in the FD training, e.g., one group played a silent visuo-spatial game, while the other groups underwent FD training with the target tone varied adaptively to track 50%, 75%, and 95% correct levels of performance. All groups were assessed before, during, and after FD training. Amitay et al. (2006) found a significant reduction in the FD threshold scores after training in all the training groups. The control group showed no improvement in FD. One of the training groups was put through FD training using identical tones. The results showed that that group demonstrated significant improvement in FD that was compatible to the groups that underwent training with adaptive procedures.

Other researchers investigated the effects of FD training using electrophysiological measures. Tong et al. (2009) examined the effects of FD training in relation to behavioural performance and ERPs in seven adults recruited from the general population. The researchers observed a significant increase in P2 ERP amplitude which correlated with significantly faster discrimination reaction time. This was observed immediately post-training and nine weeks post-training. The P2 ERP has been thought to be related to several other neural and psychological processes, as such that P2 contributes to the classification of auditory stimuli that precedes N2 and P3 responses, i.e., P2 might reflect a pre-attentive alerting mechanism (Tremblay & Kraus, 2002), or that it is involved in the inhibitory processes in preventing interference by irrelevant stimuli (Ceponiene, Alku, Westerfield, Torkia, & Townsend, 2005; Melara, Rao, & Tong, 2002). Tong et al. (2009) demonstrated that P2 is associated with the speed at which auditory perceptual representations are accessed and that this process can be enhanced through FD training. Additionally, Tong et al. (2009) found enhancement in P3 amplitude after FD training. P3 is considered to be an indication of volitional access to perceptual representation. Therefore, the researchers suggested that training could have boosted the “saliency of target deviance in working memory, making them more available to awareness during active attention” (p. 85).

Menning, Roberts and Pantev (2000) examined changes in the slow auditory evoked potential (wave N1m) and mismatch field (MMF) following FD training in 10 adults recruited from the general public. N1m and MMF, the neuromagnetic equivalence of the N1 ERP and MMN are thought to reflect pre-attentive perception and frequency specific AP respectively (Tong et al., 2009). Menning et al. (2000) found that the significant improvement in FD after training was associated with a significant increase in the amplitude of N1m and MMF responses. Since both N1m and MMF are cortical-evoked potentials, Menning et al. (2000) postulated that training had resulted in the plastic reorganization of the cortical representation for the trained stimuli.

Given the above evidence that FD can be improved in adults through training and the association between FD and literacy and language abilities, it is important to investigate whether similar training effects can be observed in children and whether such effects generalise to literacy and language abilities. Before embarking on such a study (STUDY 1 of this thesis), a second systematic review was conducted to investigate the effect of FD training in children.

This systematic review included studies that involved children recruited from the general population, and children in the APD, SRD, and SLI populations. The studies with children from the general population were included because the intervention literature concerning FD training in APD, SRD, and SLI is limited at the time of writing the current thesis. The specific questions underlying the systematic review were:

1) Does FD improve by training in typically developing children recruited from the general population?
2) Does FD improve by training in children with APD, SRD, or SLI?
3) Does the (potential) effect of FD training generalise to language and reading ability in typically developing children, and in children with APD, SRD, or SLI?

### 2.4.2 Methods

A systematic search of five databases (Medline, PsychInfo, Eric, Informit, and Google Scholar) was conducted for articles concerning FD training in children with APD, SRD, and SLI, and children recruited from the general population. The key words used were the pairing of the terms ‘frequency discrimination’ or ‘pitch discrimination’ with ‘intervention’, ‘training’, or ‘therapy’. The search was limited to peer-reviewed articles concerning children aged 6 to 18 years that were published between 1990 and 2013. Only intervention studies that involved the manipulation of stimulus frequency as the key manipulation were included. Additionally, the effect of FD training had to be separable from the effect of other training regimes that might also have been investigated. Only articles in English were included. Studies involving participants with cochlear implants, visual impairment, intellectual disability, epilepsy, and autism were excluded from this review. The outcome of each eligible study was summarised and evaluated for its methodological quality, while the level of evidence was rated according to the guidelines stated in Section 2.2.1 of this thesis.

### 2.4.3 Results

The initial search revealed 205 citations which were evaluated on the basis of their titles and abstracts (see Figure 2.2). Twelve citations were initially accepted. After a review of the full text of these articles, four citations out of the 12 which documented five studies were excluded (Murphy, 2011; Schäffler et al., 2004; Schochat et al., 2010; Sharma et al., 2012). Of these, three citations (documenting four studies) were excluded because they incorporated FD training as part of a broader intervention regimen which also targeted other AP abilities (e.g., intensity discrimination, gap detection, and temporal training) (Schäffler et al., 2004; Schochat et al., 2010; Sharma et al., 2012). These studies were excluded because the effects of FD training could not be isolated from the effects of training that targeted other AP skills. Two of these four studies were the only studies that involved children with APD (i.e. Schochat et al., 2010; Sharma et al., 2012). Lastly, Murphy

(2011) was excluded because the intervention did not involve the manipulation of stimuli frequency as the prime manipulation, but instead focused on the training of temporal order detection

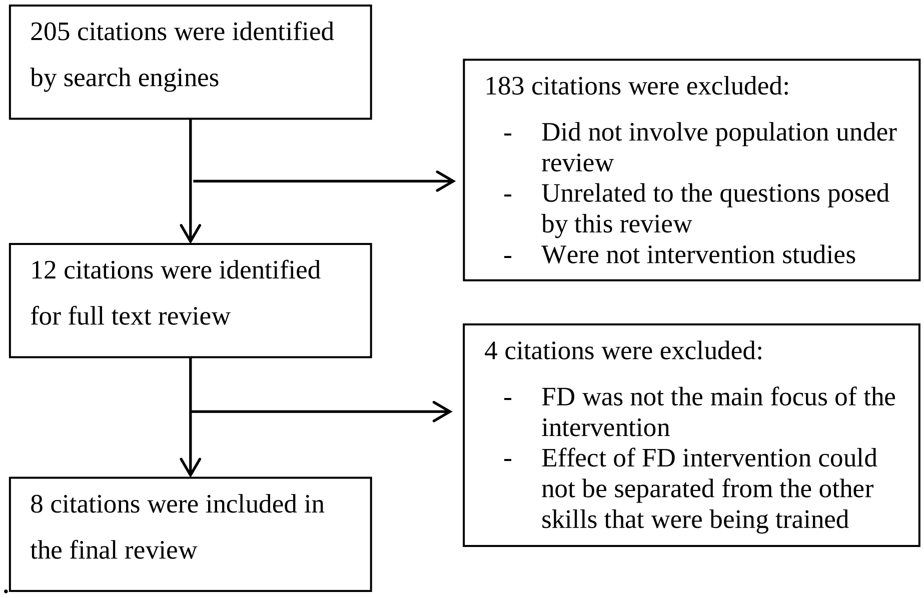



**Figure 2.2: Flow chart of the identification process of articles for review**

A total of eight studies documented in seven citations met all the selection criteria (Halliday et al., 2008; Halliday, Taylor, Millward, & Moore, 2012; McArthur et al., 2008; Millward, Hall, Ferguson, & Moore, 2011; Moore et al., 2008; Moreno & Besson, 2005; Sutcliffe, 2006). Of these, five citations documenting six studies investigated FD training in children recruited from the general population (Halliday et al., 2008; Halliday et al., 2012; Millward et al., 2011; Moore et al., 2008; Moreno & Besson, 2005). The remaining two of the eight studies investigated FD training in children with SRD and SLI (McArthur et al., 2008; Sutcliffe, 2006).

All studies explored FD training in the context of psychoacoustic tasks, except for Moreno and Besson (2005), where FD training was conducted using a music training program, named ‘The Musical Garden’, developed by Napoleoni and the Machin’Art association. Table 2.10 displays a summary of the eight studies, including information on the criteria for participant selection, the age groups of the participants, the numbers of participants, types of intervention, the intervention schedule and duration, and study outcomes in terms of AP, language, and literacy abilities. Table 2.11 summarises the level of evidence and methodological quality of each study. The presence and direction of statistically significant comparisons and effects are reported in the tables with the following annotations:

1) ‘+’ indicates that at least one statistically significant outcome ($\alpha$ =0.05) in favour of intervention was found, either as the result of pre- and post-intervention comparison(s), or as the result of between-group comparison(s) with a (matched) control group;
2) ‘0’ indicates the reporting of one or more non-significant outcomes; and
3) ‘-’ indicates the reporting of one or more negative outcomes, i.e., significantly poorer post-intervention performance was observed in at least one measure. Studies that employed more than one outcome measure for a particular hypothesis were eligible for all three signs.

**Table 2.10: Summary of studies of FD training in children (page 1 of 2)**

| Reference | Age (y;m) | N | Tx groups (n) | Schedule | Improved FD? | Improved PP? | Improved language? | Improved Reading? | Improved Spell? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Moore et al., 2008): Study 1** | 8;0-9;0 | 29 GP | FD (29) | Single 3 hour session | 0 | NT | NT | NT | NT | NR |
| **(Moore et al., 2008): Study 2** | 8;0-9;0 | 10 GP | FD (10) | 30 mins<br>3 x per week<br>4 weeks | + | NT | NT | NT | NT | NR |
| **(Halliday et al., 2008)** | 6;0-11;0<br>19;0-40;0 | 70 GP<br>30 GP | FD (100) | Single 3 hour session | +, 0 | NT | NT | NT | NT | NR |
| **(Halliday et al., 2012)** | 8;0-10;0 | 86 GP | FD (22)<br>PD (22)<br>VD (20)<br>NI (22) | 30 mins<br>3 x per week<br>4 weeks | +<br>0<br>0 | 0<br>0<br>0 | NT | 0<br>0<br>0 | NT | NR |
| **(Millward et al., 2011)** | 8;0-10;0 | 41 GP | FD (10)<br>FDN (10)<br>WN (11)<br>NI (10) | 30 mins<br>4 weeks<br>12 sessions | +<br>+<br>0 | NT | NT | NT | NT | NR |

KEY: GP = General population; FD = Frequency discrimination training (auditory); PD = Phonetic discrimination training; VD = Visual discrimination; FDN = Frequency discrimination in modulated noise; WN = mono-syllabic words in modulated noise; NI = No intervention; NT = Not tested; NR = Not reported; '+' = one or more effects favoured the treatment, '0' = one or more non-significant treatment effects, and '–' = one or more effects favouring the pre-intervention measurement or controls.

**Table 2.10: Summary of studies of FD training in children (page 2 of 2)**

| Reference | Age (y;m) | N | Experimental groups (n) | Schedule | Improved FD? | Improved PP? | Improved language? | Improved Reading? | Improved Spell? | Sig. effect? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Moreno & Besson, 2005)** | 8;0 | 20 GP | Pitch Proc (10) | 8 weeks | + | NT | NT | NT | NT | NR |
| | | | Painting (10) | | 0 | | | | | |
| **(McArthur et al., 2008)** | 6;0 to 15;0 | 20 SRD | FD (18 SRD/SLI)* | 30mins | + | NT | 0 | 0, 0 | 0 | NR |
| | | 8 SLI | RAP (3 SRD/SLI) | 4 x per week | NT | | 0 | 0, 0 | 0 | |
| | | 36 Typical | VD (4 SRD/SLI) | 6 weeks | NT | | 0 | 0, 0 | 0 | |
| | | | CVD (9SRD/SLI) | | NT | | 0 | 0, 0 | 0 | |
| | | | NI (32-36 Typical)** | | | | | | | |
| **(Sutcliffe, 2006)** | 6;4 | 1 SRD w ADHD | FD (1) | (duration not specified) 6 sessions 2 weeks | 0 | + | NT | 0, NR | NT | NR |

*24 of the 28 children with SRD/SLI were trained on one task; 2 SRD and 2 SLI were trained on two tasks

** the numbers of controls varied across the experimental conditions

KEY:

GP = General population; Pitch Proc = Pitch processing training; SRD = Specific reading disorder; SLI = Specific language impairment; ADHD = Attention Deficit Hyperactivity Disorder; FD = Frequency discrimination training; RAP = Rapid auditory processing training; VD = Vowel discrimination training; CVD = Consonant vowel discrimination training; NI = No intervention; NT = not tested; NR = not reported; ‘+’ = positive outcome for the experimental condition; ‘0’ = non-significant outcome; ‘-’ = negative outcome of experimental condition

**Table 2.11: Levels of evidence and the methodological assessment of the studies of FD training in children**

| Reference | Levels of Evidence (points awarded) | Study protocol | Blinding? | Random allocation? | Intervention fidelity? | Significance testing? | Reporting of effect sizes? | Incomplete data addressed? | Intention to treat? | Free of selective reporting? |
|---|---|---|---|---|---|---|---|---|---|---|
| **(Moore et al., 2008): Study 1** | III (4/7) | Adequate | No | N/A | Yes | Yes | No | Unclear | N/A | Yes |
| **(Moore et al., 2008): Study 2** | III (4/7) | Adequate | No | N/A | Yes | Yes | No | Unclear | N/A | Yes |
| **(Halliday et al., 2008)** | III (5/7) | Adequate | No | N/A | Yes | Yes | No | Yes | N/A | Yes |
| **(Halliday et al., 2012)** | IIa (7/8) | Adequate | Yes* | Yes** | Yes | Yes | No | Yes | No | Yes |
| **(Millward et al., 2011)** | IIa (5/8) | Adequate | Yes* | No | Yes | Yes | No | No | No | Yes |
| **(Moreno & Besson, 2005)** | IIb (3/8) | Inadequate | No | No | Yes | Yes | No | No | No | Yes |
| **(McArthur et al., 2008)** | IIa (4/8) | Adequate | No | No | Yes | Yes | No | Unclear | N/A | Yes |
| **(Sutcliffe, 2006)** | III (2/7) | Inadequate | No | N/A | Yes | No | No | Yes | N/A | No*** |

* Testers were blinded to pretesting results but not to experimental conditions. ** Random allocation was stratified according to gender, year group and native English status.

*** The post-training outcome of the FD task was not reported.

### 2.4.4 Discussion

#### *2.4.4.1 Does FD improve by training in typically developing children recruited from the general population and in children with SRD or SLI? (Questions 1 and 2)*

The outcomes of the systematic review suggest that FD can be improved by training. Five out of the eight studies (Halliday et al., 2012; McArthur et al., 2008; Millward et al., 2011; Moore et al., 2008; Moreno & Besson, 2005) reported significant improvement in FD ability after FD training, either in terms of a significant improvement across pre-post performance, and/or a significant improvement compared to controls who did not receive FD training. For instance, Halliday et al. (2012) conducted a stratified-randomised controlled trial involving 86 children. Twenty-two children were allocated to the FD training group, 22 to the phonemic discrimination training group, 20 to the visual discrimination training group, and 22 were allocated to the no-intervention control group. This study was rated as evidence level Ib and received a quality rating of seven out of eight points. The authors reported that the group of participants who received FD training showed significant pre - post training improvement on FD, which was significantly lower (better) than the FD threshold scores achieved by the other three experimental groups, one of which was the no intervention control group, while the other two groups undertook other interventions, namely, phonetic discrimination intervention and visual discrimination intervention.

Millward et al. (2011) conducted a quasi-experimental study involving two types of FD training (i.e., FD training in the absence of background noise, i.e., the FD group, and FD training in modulated noise, i.e., the FDN group). They also included a control group that did not receive FD training. This study was rated as evidence level IIa, and received a quality rating of five out of eight points. The two groups that underwent FD training showed significant pre- and post-training improvement on the training task. Both groups showed significantly greater improvement than the control group. Similar findings were shown in the other two studies (Moore et al., 2008; Moreno &

Besson, 2005). Moore et al. (2008) demonstrated significant improvements in FD after training in a single group of 10 children recruited from the general population. Lastly, Moreno and Besson (2005) demonstrated that a group of children, recruited from the general population, who underwent pitch processing training, showed significant improvement in the accuracy and reaction time of pitch discrimination when compared to the control group of children who undertook painting lesson of the same duration.

McArthur et al. (2008) conducted a multi-group, quasi-experiment investigating the effect of a range of AP training. This study was rated as level IIa evidence with a quality rating of four out of eight. Twenty-eight children with AP deficits underwent training. Twenty had SRD and eight had SLI. Of these, 18 children were found to have a FD deficit and subsequently underwent FD-training. These children achieved significant improvement in their FD threshold after training compared to the no-intervention control group.

However, three of the eight studies reported non-significant training effects (Halliday et al., 2008; Moore et al., 2008; Sutcliffe, 2006). Halliday et al. (2008) found that FD can be improved by training in *some* but not *all* children. They investigated the effect of FD training in 70 children aged 6-7 years, 8-9 years, 10-11 years, and a group of 30 adults who served as controls. All participants were recruited from the general population. All participants undertook three hours of FD training and were subsequently retested. The children were classified into three sub-groups based on their FD performance and training outcomes: 1) the ‘adult-like’ group, who achieved threshold scores similar to those of the adults even before training; 2) the ‘trainable’ group, who were able to achieve threshold scores similar to those of the adults after training; and 3) the ‘non-adult-like’ group, who were unable to obtain threshold scores similar to those of the adults, even after training. The data from these three subgroups were further analysed for characteristics such as age, non-verbal intelligence, and attention. The authors found that the children in the non-adult-like group were on average younger than those in the adult-like group, the majority were aged between 6 and 7 years. The non-adult-like group of children also showed significantly lower non-verbal intelligence and poorer attention than the adult like group. The authors concluded that cognitive maturation and attention affected the FD training outcomes. Moore et al. (2008) conducted a second study investigating the effects of FD learning in a single group of children, aged 8 to 9 years, who were recruited from local schools. The children undertook 3 hours of FD training; their performance was found to be erratic throughout the training, also showing no evidence of a beneficial training effect.

Lastly, Sutcliffe (2006) conducted a single-case study concerning the effects of FD training in a child with comorbid SRD and ADHD. The child (6;4 years old) showed elevated FD threshold scores and poor non-word reading ability prior to training. The child received six sessions of FD training over two weeks. Sutcliffe reported that the child's FD performance was variable and inconsistent throughout the training. Post-intervention assessment revealed no improvement in FD ability or in non-word reading. However, improvement was observed on another task, frequency modulation, which required spectral discrimination. Further assessments were conducted after the child was put on stimulant medication for ADHD. From this point, the child showed a large reduction in his FD threshold score which remained stable across the repeated assessments that occurred over a four-month time-span after the FD training.

The above studies demonstrate that various factors might contribute to non-significant training outcomes on FD. One factor might be that the duration of the training was insufficient to cause any change in performance. Both Halliday et al. (2008) and Moore et al. (2008) had their participants undergo a single 3-hour training session. However, all the studies that reported a significant positive training effect had their participants undergo multiple 30 minutes sessions over a few weeks. Therefore, a single, prolonged training session might be ineffective for improving FD ability in children. It could be difficult for children to maintain attention and motivation for such an extended period of time, which could have affected their engagement in the training and performance on retesting. In Sutcliffe's case study, the child received six training sessions over two weeks. However, the duration of the sessions or the number of trials conducted during each training session were not specified. The article states that "the auditory training sessions involved repeated testing over 2 weeks on two FD tasks (which employed target tones of different durations – 50 ms and 150 ms)" (Sutcliffe, 2006 pp. 202) – (note: author's parentheses). This could imply that the 'training sessions' were rather brief and/or contained minimal trials on both tasks because they were conducted as 'tests'. The minimum number of hours of total training time noted in the studies was approximately 12 hours, which is well beyond the one session of 3 hours in the study by Moore et al. (2008).

Other factors that could affect performance on FD tasks might also have an effect on training outcomes, such as age, intelligence, and attention (see Section 2.3.2 of this introduction). For instance, Halliday et al. (2008) reported that the children who were in the 'non-adult-like' group, who did not respond to FD training, were generally in the younger age group (6 to 7 years old). They also had significantly lower non-verbal intelligence and poorer attention than the adult-like group. Similarly, the child in Sutcliffe et al. (2006) case report was a younger child (6;4 year old) and had poor attention indicated by the comorbid diagnosis of ADHD.

In summary, these studies provide evidence that FD ability can be improved in some children. However, limited training benefits are seen in others. These findings are in line with those reported in McArthur and Hogben (2011). Upon reanalysis of their data in the 2008 study, McArthur and Hogben (2011) reported that children who demonstrated poor performance on psychoacoustic tasks might respond differently to training. Four types of performance categories were observed: 1) children with errant performance that improved with training; 2) children with errant performance that did not respond to training; 3) children with non-errant poor performance that improved with training; and 4) children with non-errant poor performance that did not respond to training. These different responses to training have been found to be associated with age, intelligence, and attention.

##### *2.4.4.2 Does the effect of FD training generalise to language and reading ability in typically developing children, and in children with APD, SRD, or SLI?*

Only two of the eight studies explored the generalisation of FD training to the cognitive tasks of literacy and language. Halliday et al. (2012) explored this issue in children recruited from the general population. Despite significant improvement on FD after training, no generalisation effect was observed regarding phonological processing and reading ability. The limitation of this study is that it is unclear what the phonological processing and reading ability of these children were prior to the training. It is possible that the group mainly consisted of good readers. If this was the case, then there might have been a ceiling effect on phonological processing and reading prior to FD training, limiting any post-training gains.

McArthur et al. (2008) investigated the generalisation effect of FD training in children with SRD and/or SLI. Again, despite the significant improvements in FD observed in the FD training group, there was no evidence of an intervention-related generalisation effect to language and reading. Both training group and the control group showed significant improvements in the post-intervention language and reading scores. This suggests that the changes in performance were no greater than the test-retest effect.

However, generalisation effects to reading or language ability have been noted in two studies in which the training effects of non-speech or simple speech sounds training were investigated, e.g., Strehlow et al. (2006) and Schäffler et al. (2004). Unfortunately, these studies did not meet the selection criteria for the current review because FD training was not part of the intervention (Strehlow et al., 2006), or because FD training was part of an intervention program in which other AP skills were also trained, so that the effect of FD training could not be isolated (Schäffler et al., 2004). Both studies involved children with SRD. The authors of both studies reported a significant improvement in phonological processing, reading, and spelling abilities. It is important to note that these studies simultaneously trained reading and spelling as well as AP. Thus, gains noted on the reading and spelling measures could have been the result of the reading and/or spelling training component of the intervention program. Therefore, these studies do not provide evidence of the generalisation effects of FD training *per se*.

McArthur et al. (2008) proposed that the training of AP skills might help children *to learn* reading, spelling, and language, but not necessarily improving their ability to *do* reading and spelling or spoken language tasks. They suggested that when a child shows poor speech processing and poor knowledge of phoneme-grapheme mapping due to poor AP, and the child undertakes AP training until their AP ability is ‘normal’, their speech processing ability would become ‘normal’ too. However, this will not automatically make them proficient at mapping graphemes with phonemes, which was demonstrated by the lack of a generalisation effect for the reading and language tasks following FD training in their study. However, the training of AP skills could help children to become more ready to learn reading and language skills with appropriate tuition. This proposition does not appear to have been tested to date.

In summary, there is evidence showing that FD ability can be improved by training in children. However, training outcomes might differ between individuals, depending on factors such as the individual’s cognitive maturity, intelligence, and attention. There is limited evidence to date that improved FD generalises to improve literacy and language abilities. However, as proposed by McArthur et al. (2008), FD training could improve speech processing ability in children with FD difficulties. This, in turn, might improve the child’s readiness to learn literacy and language.

The second study (STUDY 2) in this thesis is designed to address this proposition. The overarching aim is to investigate whether improved FD enhances the effect of phonological processing training (PP training) in children diagnosed with APD who showed FD and reading difficulties at the start of the study. Firstly, the outcomes of two intervention programs were investigated in isolation: 1) a computer-based psychoacoustic program for FD training, and 2) a computer-based intervention program to improve PP. The subsequent aims were: 1) to investigate the effect that prior FD intervention might have on the outcomes of the subsequent PP intervention; and 2) in the case that intervention-specific effects were found, whether they would be specific to

FD intervention or a result of intensive exposure to, and familiarity with, a computer program. Generalisation of the intervention-specific effects is also studied in terms of: (3) generalisation to a different, yet equivalent test of FD, and generalisation to phonological processing; and (4) generalisation to general language and literacy skills, in particular, word reading, receptive vocabulary, and receptive grammar.

Thereby, the two studies in the present thesis focused on investigating the potential effects that AP ability could have on cognitive functions, such as reading and language. The aim of STUDY 1 was to investigate whether children with APD who also demonstrated FD difficulty would differ in terms of their abilities in reading, language, attention, and executive control to children with APD who showed age-appropriate FD, and the focus of STUDY 2 was to investigate whether FD intervention would have independent effects in improved reading and language, and whether it might enhance the outcome of the subsequent phonological processing intervention.

# 3 STUDY 1: METHODOLOGY

## 3.1 Aim of STUDY 1

Recent studies have found that poor(er) FD might be associated with poor(er) reading ability, receptive language, and other cognitive abilities, such as attention and executive control. The aim of STUDY 1 was to investigate whether children with APD and poor FD differed from other children with APD who had age-appropriate FD ability on tests for phonological processing, word reading, language, auditory sustained attention, and executive control.

## 3.2 Specific research question for STUDY 1

The specific research question for STUDY 1 was: were there significant differences between the phonological processing abilities, word reading abilities, receptive language skills, auditory sustained attention, and executive control of children with APD who also showed FD difficulty, and those with APD but without FD difficulty?

## 3.3 Study Design

STUDY 1 was a case-control study where the performance on assessments of phonological processing, word reading, receptive language, auditory-sustained attention, and executive control of children with APD and FD difficulties (i.e., the FD-DIFF group) was compared with those who have APD but age-appropriate FD (i.e., the FD-WNL group).

## 3.4 Recruitment

Participants were recruited from the public and private APD clinics at Flinders University, and a private audiology clinic in Adelaide, the Adelaide Hearing Consultants (see Section 3.6 for further details on the APD diagnostic assessment procedure used by the participating clinics). Information about the study was sent out via mail to carers of the children who had been diagnosed with APD within the previous 12 months. The mail also included the Participant Information Sheet (Appendix A), which outlined the purpose of the study and the procedure involved, the Consent Form (Appendix B), and a form for recording contact information (the Personal Details Form, Appendix C). Parents indicated their interest to participate in the study by contacting the investigator or by returning the Consent Form and the Personal Details Form. The recruitment process covered both STUDY 1 and STUDY 2 of the current thesis.

Sixteen children participated in the study. Eight with FD difficulty (four boys and four girls, aged 7;5 to 9;9 years, mean age = 8.84 years, SD = 0.79), i.e., the FD-DIFF group, and another eight age-matched children with typical FD ability (six boys and two girls, aged 7;1 to 10;2 years, mean age = 9.12 years, SD = 1.16), i.e., the FD-WNL group. All participants were assessed to have normal non-verbal intelligence, and had been diagnosed with APD within 12 months of their participation in the study.

## 3.5 Inclusion and Exclusion Criteria

### 3.5.1 Inclusion criteria for the FD-DIFF group

Children were included if they were:

- Aged between 7;0 years and 10;11;
- Had a recent APD diagnosis from one of the three participating audiology clinics;
- Showed FD difficulty based on their performance on the SoundsPod, a computer-based psychoacoustic test (see Section 3.9.4 for details about the SoundsPod) (McArthur et al., 2008) and the normative data established in McArthur et al. (2008);
- Had English as their first language or as one of their first languages.

### 3.5.2 Inclusion criteria for the FD-WNL group

These were the same as above, except that these children did not show FD difficulty as tested on the SoundsPod, i.e., they performed within the test norms.

### 3.5.3 Exclusion criteria for both groups

Children were excluded if they:

- Had a reported history or a known diagnosis of chronic medical or neurodevelopmental conditions, such as epilepsy, cerebral palsy, autism spectrum disorder, pervasive developmental disorder, intellectual disability, or a history of head injury;
- Had major sensory impairments, such as a visual impairment (excluding correction by glasses) and/or peripheral hearing loss.

Children could have co-morbid language difficulty, reading difficulty, Attention Deficit Disorder (ADD), or ADHD. Two of the sixteen children scored in the lowest 10% on one or more of the language assessments. Based on the diagnostic criteria for SLI published in Bishop (2006)[9], these two children (one in the FD-WNL group and the other in the FD-DIFF group) would have satisfied the criteria for a positive SLI diagnosis. Additionally, based on the criteria for reading deficit published in the Assessment of Lexical and Non-lexical Reading Ability in Children (ALNLRAC), three of the sixteen children showed performance consistent with those with a reading deficit[10]. All three of these children were in FD-DIFF group. However, it is noteworthy that all sixteen children in the current sample were reported as having reading difficulties by their carers. Lastly, none of the children in the current sample had a reported diagnosis of ADHD or ADD.

[9] The criteria for a positive SLI diagnostic include a standard score in the lowest 10% on a standardised test of expressive and/or receptive language in conjunction with nonverbal IQ and other nonlinguistic aspects of development fall broadly within the normal limits, and that language difficulties cannot be accounted for by hearing loss, physical abnormality of the oromotor structures, or environmental deprivation. Additionally, language difficulties could not be explained by brain damage (Bishop, 2006)

[10] This was defined as a score within Band A of the ALNLRAC in the reading of regularly spelt words, irregular spelt word and/or non-words (see Coltheart and Leahy, 1996 for further details).

### 3.6 Diagnostic criteria used for APD

The APD diagnostic criterion used in this study is consistent with the guidelines of the ASHA (2005), that is: a performance of at least two standard deviations (SD) below the mean on two or more tests in the APD test battery. Table 3.1 shows the core and supplementary tests used in each of the three clinics.

**Table 3.1: Details of the tests used in the APD diagnostic clinics**

| | Clinic 1 | Clinic 2 | Clinic 3 |
|---|---|---|---|
| **Core Tests** | Competing Sentence Test<br>Digit Forward<br>Digit Reversed<br>Sentence Recall<br>Staggered Spondaic Word Test | Competing Sentence Test<br>Dichotic Digits<br>Frequency Pattern Test<br>Random Gap Detection Test | Competing Sentence Test<br>Digit Span Test<br>Sentence Recall Test<br>Staggered Spondaic Word Test |
| **Supplementary Tests** | Filtered Word (SCAN-C)<br>Auditory Figure Ground (SCAN-C)<br>Dichotic Digits Test<br>Random Gap Detection Test<br>Pitch Pattern Test<br><br>Minimal Masking level Difference<br>LISN-S<br><br>Non-Word Repetition Test<br>Wepman Sound Discrimination Test | Low-Pass Filtered Speech (NU6 1kHz LP filtered)<br>Time-Compressed Sentence Test<br>Staggered Spondaic Words Test<br>Gaps in Noise Test<br>Masking Level Difference Test (500Hz)<br>LISN-S | Double Digits version of the Dichotic Digits Test |

### 3.7 Equipment and Assessment Procedure

A DELL Latitude D830 laptop (Pentium 4, 2GHz CPU, 512M RAM, run on Windows XP Professional) was used to present the computer-based tasks. Audio stimuli were presented via an external sound card (Creative SoundBlaster X-Fi Go!) through noise attenuated headphones (Sennheiser HD 202).

The participants were first screened for hearing and near vision acuity to rule out any potential peripheral hearing and near vision impairment (with the exception of the use of glasses). Subsequently, the tests were presented in random order. The name of each test was written on identical pieces of paper and placed face down on the table. The child randomly selected a ‘card’ and undertook the test that was specified on the card. On completion of this test, the child selected another card and undertook the next assessment and so on. The assessment took approximately 3 hours to complete with breaks given when required. The assessment sessions took place in a quiet room at the Speech and Audiology Clinic at Flinders University or in the participant’s home.

## 3.8 Chronological Age

The age range chosen was determined by considering the minimum age at which a reliable APD diagnosis can be made. It is recognised that APD cannot be reliably diagnosed in children below the mental age of seven years (Moore et al., 2011). The task difficulty and performance variability in children below the mental age of 7 years renders questionable results on behavioural tests of central auditory function (ASHA, 2005). Studies have shown repeatedly that children below the age of 7 years find psychoacoustic tasks, such as FD, difficult (Moore et al., 2011; Sutcliffe & Bishop, 2005; Thompson et al., 1999). The mean age of the FD-DIFF group was 8.84 years (SD = 0.79) and the mean age of the FD-WNL group was 9.12 years (SD = 1.16) (see Table 4.1).

## 3.9 Inclusion Assessments

### 3.9.1 Peripheral hearing screening: Materials and procedure

It is recognised that peripheral hearing impairment and APD may co-exist (AAA, 2010; ASHA, 2005). Therefore, peripheral hearing screening was included as part of the participant selection procedure to identify children with suspected hearing loss. Children who failed the screening would be excluded from the study. The hearing screening was conducted using a portable audiometer (Amplivox 160, with TDH49P headphones and noise-excluding Audiocaps). Hearing sensitivity was screened using monaural presentation of pure tones at frequencies of 500Hz, 1000Hz, 2000Hz, and 4000Hz, and at a screening level of 20dB HL. Each ear was tested separately. The tones were presented at random intervals starting at 1000Hz, then 2000Hz, 4000Hz, and 500Hz. The child indicated that he/she had heard the sound by pressing a response button. Up to three presentations of tones at each frequency were delivered. The child passed the screening if he/she could detect the tones twice in the three presentations. The peripheral hearing screening took approximately 5 minutes to complete. This protocol was consistent with the published guidelines of ASHA (1997) and the American Academy of Paediatrics (2003). All participants passed the peripheral hearing screening.

### 3.9.2 Visual acuity: Materials and procedure

The near vision chart was created by Pilot Medical Solutions (2001) and retrieved from http://www.leftseat.com/pdffiles/nearv1.pdf. The chart consisted of numerical digits and letters of the alphabet as symbols. Near visual acuity screening was included to identify those at risk of having difficulties reading or seeing objects up close (approximately 40cm from the eye) due to (uncorrected) visual impairment. A separate sheet containing these numbers and letters printed in a large font size was presented to the child prior to the screening. This was to ensure that the child was familiar with the names of the numbers and letters used.

During the screening, the near vision chart was placed 40cm from the child’s eyes and each eye was tested separately. The child read aloud the numbers and letters on the vision chart, line-by-line, while covering one eye. Those with prescribed glasses were screened with their glasses on. Visual acuity was recorded as the last line on which more than half of the symbols were identified correctly. Those who had difficulty seeing the items on the 20/30 line in either or both eyes, or those who had a two-line difference in their ability to read with each individual eye, were excluded from the study.

The near vision screening took approximately 2 to 3 minutes to complete. The procedures were in line with the recommendations of the Centre for Community Child Health of the Australian State of Victoria (2008) and the Arizona Department of Health Services of the United States (2004). One child failed the near visual screening and was therefore excluded from the study. A full vision assessment was recommended. All other participants passed the near visual screening.

### 3.9.3 Nonverbal intelligence: Materials and procedure

Nonverbal intelligence was assessed using the Raven's Coloured Progressive Matrices, RCPM (Raven, 1976). The RCPM is a subsequent version of the Raven's Progressive Matrices developed by Raven in 1936. It has been considered to be one of the purest measures of 'fluid intelligence', i.e., the ability to deal with new information and non-verbal abstract reasoning, particularly for children with reading or language difficulties, as opposed to 'crystallised' intelligence, i.e., acquired knowledge (Carver, 1990; Stanovich, Cunningham, & Freeman, 1984). This test of nonverbal intelligence was included to identify and thus exclude the children with intellectual impairment. According to ASHA (2005), children with intellectual impairment can experience AP difficulties, but these difficulties are considered to be part of a more global disorder rather than APD *per se*. APD is a deficit in the neural processing of auditory stimuli that is **not** due to cognitive or other higher functional abilities. Therefore, low cognitive (nonverbal) ability was an exclusion criterion for the study.

The standardisation of the RCMP has been done in many countries around the world (see Raven et al., 1998 for details). Two normative studies were conducted with Australian children, first by Reddington and Jackson (1981), and more recently by Cotton et al. (2005). Cotton and associates collated normative data on 618 Victorian school children, aged 6;0 to 11;9 years. They compared their normative data with those collated by Reddington and Jackson and found no significant differences between their data and those of the earlier study. The normative data generated by Cotton et al. (2005) were used to assess the nonverbal intelligence of the participants in this study.

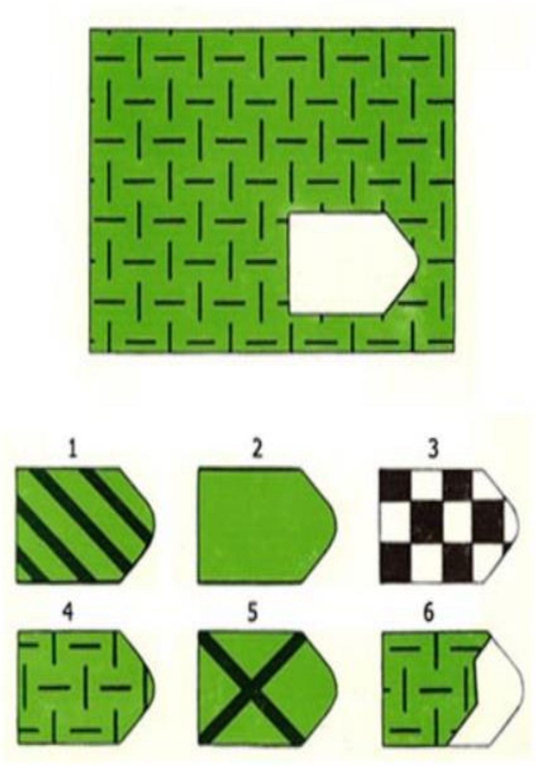



**Figure 3.1: The RCPM task (Raven, Raven, & Court, 1998). The participant was asked to determine which of the six patterns fitted the missing part of the drawing above**

The RCPM consists of three sets of stimuli (set A, Ab, and B), each containing 12 items. Each item comprised a drawing with a part missing. Six patterns are presented at the bottom of the page, one of which fits the missing part. The child’s task is to identify the pattern that completes the picture (see Figure 3.1). The test took 10 to 15 minutes to complete. It was administered according to the published instructions. Those who obtained a score below the second SD of the mean score for age were considered to have intellectual impairment.

None of the potential participants showed low nonverbal intelligence. All participants in the present study had a RCPM standard score (RCPM-SS) above the -2SD. The RCPM-SS of the participants ranged from 78.36 to 112.09 (mean = 102.01, SD = 11.87).

### 3.9.4 Frequency discrimination: Materials and procedure

The FD ability of the participants was assessed using the SoundsPod. The SoundsPod, which is a computer-based psychoacoustic task, was developed by Rob Seiler from ELR Software Pty Ltd for a research study conducted by McArthur and colleagues (2008). The study investigated the AP deficits in a group of children with reading and language difficulties. A subgroup of children underwent training for the different AP deficits using the SoundsPod, demonstrating significant improvements in these skills after the training.

The normative data were established in a pilot study reported in McArthur et al. (2008), in which the performance of 31 typically developing children, aged 6 to 12 years, was measured. These norms were used to identify children with FD difficulties in the present study. Further information about the psychometric properties of the SoundsPod is yet to be established.

The task uses a three-interval, two-alternative choice (AXB) paradigm. In other words, three consecutive tones are presented in each trial, and these consist of two standard tones and a 'different tone' (i.e., the target tone). The tones are visually depicted as three icons on a spaceship control panel: two yellow buttons and a grey speaker in the middle (see Figure 3.2). The icons pulse as the sounds are being played. The child's task is to identify the target tone by clicking the icon that corresponds to the different sound. Visual and auditory feedback is given at the end of each trial. If the response is correct, shooting stars flash across the windscreen of the spaceship. If the response is incorrect, other random objects appear. Each tone is 25ms in duration and is separated by 500ms of silence. The second tone remains as one of the standard tones throughout the 'game'. The target tone is randomly assigned to either the first tone or the third tone. The frequency of the standard tones is 600Hz. The task begins with the target tone set at 1000Hz.

The rationale for using the SoundsPod was that it is child-friendly. The testing of AP ability occurs in the context of a 'computer game'. Additionally, the parameters of the program can be adjusted so that the same task can also be used as a training program. Furthermore, normative data are available and a criterion cut-off score for poorer-than-age FD ability has been established, which was vital in the selection of the potential participants.

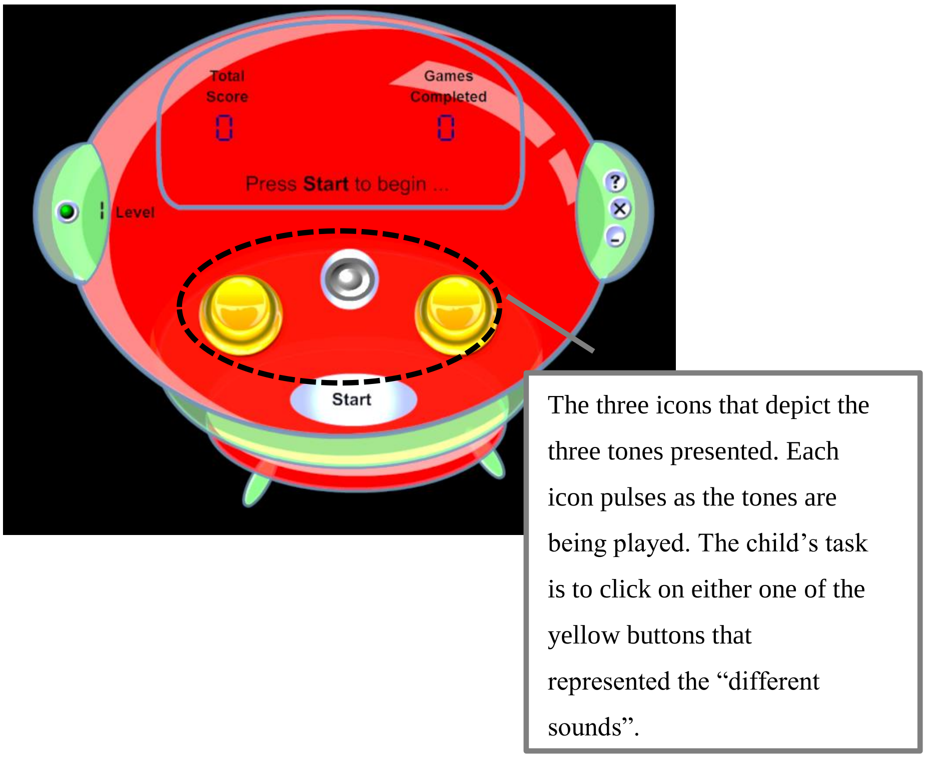



**Figure 3.2: Screenshot of the SoundsPod adapted from McArthur et al. (2008)**

A standard set of instructions was given:

"This spaceship is going to play you three sounds. Two of the sounds are the same. One of the sounds is different. I want you to tell me which sound is different. The different sound will always be played by a yellow button, which yellow button produced the different sound?"

A practice run was first conducted with the frequency of the target tone set at a clearly distinguishable level. The first trial was presented with a demonstration. The child was then given three practice trials. If they correctly identified the target tone in all three practice trials, they would commence the testing task. If not, feedback was given and the practice trials were repeated until the child responded correctly on two out of three occasions.

The game is an adaptive procedure, such that the frequency of the target tone is adjusted based on the participant's responses. The algorithm used is known as the Parameter Estimation by Sequence Testing (PEST) procedure (Taylor & Creelman, 1967). The PEST is a function which determines the amount and direction that the stimulus level would be shifted as a result of the subject's previous performance. After each presentation, the target tone is adjusted to a level where the child is able to respond correctly 79% of the time. For example, following the participant's response in a particular trial, the PEST function would calculate the accuracy of the participant's response. If the accuracy was poorer than the 79% benchmark, the frequency of the target tone in the next trial would be adjusted higher. This would result in a greater frequency difference between the standard tone and the target tone for easier discrimination. The reverse would occur if the accuracy was greater than the 79% benchmark. As the accuracy of the discrimination improves, the frequency difference between the target tone and the standard tones is reduced, and the tones become harder to discriminate.

The frequency of the target tone corresponds to the different 'levels' on a stimulus continuum, ranging from Level 0 to 200. The frequency of the standard tone is 600Hz, and it is referenced as Level 0. The frequency of the target tone can vary from level 0 (i.e., being the same frequency as the standard tone at 600Hz), to level 200 (i.e., 400Hz higher in frequency than the standard tones, at 1000Hz). 1-unit of change in frequency or 'step-size' (e.g., from level 2 to level 1) equates to a frequency reduction of 2Hz, which is the smallest unit of change or 'the smallest step-size'. The largest step-size is a step-size of 50, which equates to 100Hz. The task begins with the largest step-size until an error is made and then a reversal in response adjustment occurs and the frequency difference between the standard tone and the target tone increases. The PEST algorithm would govern the change in step sizes based on the child's response. The task ends when the participant has made 10 reversals in response adjustment or has completed 60 trials (i.e., the maximum number of trials possible in a game). The task took 10 to 15 minutes to complete.

A threshold score is generated at the end of each game which is an indication of the child's FD ability. The threshold score is the mean frequency difference between the target and the standard tone from the $6^{th}$ to $10^{th}$ reversal in response adjustment. If a child does not make 10 reversals, the threshold score would be calculated as the average frequency difference between the standard tone and the target tone over the last 25% of trials.

The child's threshold score was compared to the mean threshold score for their age based on established normative data (see McArthur et al., 2008; McArthur & Hogben, 2011 for details on the development of age norms). If a child's score was significantly higher (i.e., poorer) than the criterion cut-off threshold score for age-typical FD ability, they were placed in the FD-DIFF group. If their threshold score was below the criterion cut-off score, they were allocated to the FD-WNL group. The task parameters and administrative procedure used was the same as those used in McArthur and colleagues' original study (2008).

## 3.10 Outcome Measures

### 3.10.1 Assessment of receptive vocabulary: Materials and procedure

Receptive vocabulary was assessed using the Peabody Picture Vocabulary Test, 4$^{th}$ Edition, PPVT-4 (Dunn & Dunn, 2007). The PPVT-4 is a standardised receptive vocabulary assessment for children and adults. The test has two parallel versions ('Form A' and 'Form B'). The PPVT-4 was chosen because it is a norm-referenced test which is widely used in research and clinical settings. It has well-established psychometric properties. Ample information about the standardisation and the psychometric qualities of the PPVT-4 can be found in Dunn and Dunn (2007).

#### *3.10.1.1 Test procedure of the PPVT-4*

The test consists of two practice items followed by 228 test items. Each test item involves the presentation of four coloured pictures on a single page. The participant's task is to select the picture that best illustrates the meaning of a stimulus word spoken by the examiner. The standard verbal prompt, "Point to (test stimulus)", was used when presenting each item.

The test items are arranged in sets of 12, in order of increasing difficulty. The initial part of the assessment involves establishing a basal score. The assessment begins at the set that corresponds to the child's age. If the child makes one or no errors in this set, then the basal score is established. If not, the examiner proceeds to the previous set of test items. After establishing the basal score, the examiner proceeds with the next set until a ceiling score is established. Testing would end when the examinee has made eight or more errors in a particular set of test items. The test was administered in accordance with the guidelines in the test manual.

As previously mentioned, the PPVT-4 has two parallel forms. Both forms were used in the present study. The children were randomly assigned to either of the forms during the assessment and the alternate form was used in the subsequent assessment session if the child continued their participation in Study 2. The PPVT-4 took 15 to 20 minutes to complete.

#### *3.10.1.2 Scoring of the PPVT-4*

The raw score was calculated by subtracting the basal score from the ceiling score. The raw score was used in the data analysis, rather than the standard score, because the FD-DIFF and the FD-WNL groups were age-matched.

### 3.10.2 Assessment of receptive grammar and sentence comprehension: Material and procedure

Receptive grammar and sentence comprehension were assessed using the Test of Reception of Grammar (TROG) (Bishop, 1989). The TROG is used to assess the child's ability to comprehend a number of different grammatical forms and sentence structures in English. It was chosen because it is a norm-referenced test that is routinely used in clinical settings and research. It has well-established psychometric properties, and further information on the test can be found in Bishop (2003).

#### *3.10.2.1 Test procedure of the TROG*

The test comprises two practice items and 80 items grouped into ‘blocks’ of four (i.e., there were 20 blocks in total). Each block assesses a different grammatical construct. During each trial, a page that consists of 4 coloured pictures is presented to the child. The child’s task is to select the picture that best illustrates the sentence spoken by the examiner. For example: Examiner: “Point to … ‘The boy is running.’” The participant points to the corresponding picture.

The child ‘passes’ a block if they have all four items correct. If one or more errors are made, the block is considered as ‘failed’. The assessment commences at a block of items that corresponds to the child’s age. If the child makes no error in the next five blocks, then testing continues forward until the child fails five consecutive blocks. If the child makes an error within the first five blocks of testing, then the examiner administers the earlier blocks beginning at the very first item of the assessment. The assessment took 10 to 15 minutes to complete.

#### *3.10.2.2 Scoring of the TROG*

Two types of raw scores can be calculated: 1) the number of correct items; and 2) the number of blocks passed. The raw score of the number of correct items was used in the analysis. Again, the raw score was used rather than the standard score because the FD-DIFF and the FD-WNL were age-matched.

### 3.10.3 Assessment of phonological processing: Materials and procedure

The Comprehensive Test of Phonological Processing (CTOPP) is a standardised assessment of PP in individuals aged from 5 to 24 years. The rationale for using the CTOPP was because it provides norm-referenced composite scores for the core areas of PP, including phonological awareness, phonological memory, and rapid naming, and that it is a standardised assessment that is routinely used in clinical settings and research. It has well-established psychometric properties which have been published in Wagner, Torgesen, and Rashotte (1999).

### ***3.10.3.1 Test procedure of the CTOPP***

The test comprises two versions: version one for 5 to 6 year-olds and version two for 7 to 24 year-olds. Version two was used in this study based on the age of the participants. This version comprises six core subtests: 1) Elision; 2) Blending Words; 3) Memory for Digits; 4) Non-Word Repetition; 5) Rapid Digit Naming; and 6) Rapid Letter Naming. Additionally, six supplementary subtests were also available to further assess the strengths and weaknesses of an individual's PP ability. However, only the core subtests were administered in this study.

A composite raw score is generated for each of the three domains of PP: phonological awareness, phonological memory, and rapid naming. The Phonological Awareness Composite Raw Score (CTOPP-PA-CR) is derived from the subtest score of the Elision and Blending Word subtests, the Phonological Memory Composite Raw Score (CTOPP-PM-CR) is derived from the Memory for Digits and Non-Word Repetition subtests, and the Rapid Naming Composite Raw Score (CTOPP-RN-CR) is derived from the Rapid Digit Naming and Rapid Letter Naming subtests. All the subtests were administered in accordance with the guidelines found in the CTOPP instruction manual. The assessment took 30 minutes to complete. The following presents the test procedures of the individual subtests:

#### *3.10.3.1.1 Elision subtest*

This subtest evaluates the ability to remove a specified phoneme from a word and then say the remainder of the word. The participant listens to a word spoken verbally by the examiner and then repeats that word. They are then asked to say the word again without a specific sound. For example:

Examiner: "Say 'tan'"

Participant: "tan"

Examine: "Now say 'tan' without saying the /t/."

Participant: "An"

Three practice items were presented prior to the presentation of the 20 items, which became progressively more difficult. The test ended when the participant made three errors consecutively or had completed the 20 items.

*3.10.3.1.2 Blending Words subtest*

This subtest evaluates the ability to combine phonemes to form a word. In each trial, the participant is presented with a pre-recorded word that is broken up into its separate phonemes. The participant's task is to 'join' the sounds together to say what the word is. For example:

Audio recording: "What word do these sounds make? /m/…/a/…/t/"

Participant: "mat"

Five practice items were presented prior to the presentation of 20 test items, which became progressively more difficult. The subtest ended when the participant made three errors consecutively or had completed the 20 items.

*3.10.3.1.3 Memory for Digits subtest*

This subtest is used to evaluate the ability to immediately recall a sequence of numbers presented verbally. During each trial, the participant listens to a pre-recorded number sequence and is required to repeat them in the order that they are presented. For example:

Audio recording: "3…7… 8… 4… 5"

Participant: "3…7… 8… 4… 5"

Five practice items were presented prior to the presentation of the 21 test items, which increased progressively in length (from two to eight digits). The subtest ended when the participant made three errors consecutively or had completed the 21 items.

*3.10.3.1.4 Non-Word Repetition subtest*

This subtest evaluates the ability to immediately recall non-words ranging from three to 15 phonemes. In each trial, the participant listens to a pre-recorded recording of a non-word and is required to repeat it as accurately and clearly as they can. For example:

Audio recording: “Lisashrul”

Participant: “Lisashrul”

Five practice items were presented prior to the presentation of 18 items, which increased progressively in length. The subtest ended when the participant made three errors consecutively or had completed the 18 items.

*3.10.3.1.5 Rapid Digit Naming subtest*

This subtest measures the speed with which the names of numbers can be recalled verbally. During each trial, 24 random numbers were presented. The participant’s task was to name the numbers as quickly as they could. The examiner recorded the time (in seconds) needed for the participant to complete the task. Two practice items were presented prior to the presentation of the two test trials. The subtest ended after the participant had completed the two test trials.

*3.10.3.1.6 Rapid Letter Naming subtest*

This subtest measures the speed with which the names of letters can be recalled verbally. During each trial, 24 random alphabetical letters were presented on a sheet of paper. The participant’s task was to name the letter as quickly as they could. The examiner recorded the time (in seconds) needed for the participant to complete the page. Two practice items were presented prior to the presentation of the two test trials. The subtest ended after the participant had completed the two test trials.

#### *3.10.3.2 Scoring of the CTOPP*

A raw score was generated at the end of each of the above subtests. For four of the subtests (namely Elision, Blending Words, Memory for Digits, and Non-Word Repetition), the raw score was the total number of correct responses achieved. For the Rapid Digit Naming subtest and the Rapid Letter Naming subtest, the raw score was the average time required to verbally recall the items across the two trials. The composite raw scores for phonological awareness, phonological memory, and rapid naming were used in the data analysis.

### 3.10.4 Assessment of word reading: Materials and procedure

Word reading ability was assessed using the Assessment of Lexical and Non-Lexical Reading Ability in Children (ALNLRAC) (Coltheart & Leahy, 1996), which is a modified version of the Word/Non-Word Tests developed by Castles and Coltheart (1993). It was included because it allows for the evaluation of reading ability of different word types, namely, regularly spelled words (hereafter referred to as 'regular words'), irregularly spelled words (hereafter referred to as 'irregular words') and non-words. The test is norm-referenced and normative data based on Australian children are available.

Two standardisation studies (Coltheart & Leahy, 1996; Edwards & Hogben, 1999) have been conducted which provided normative data for Australian children (aged 7 to 12 years). The normative data published in Edwards and Hogben (1999) were used in this study. This set of normative data consisted of Coltheart and Leahy's (1996) original sample of 420 school-children from the metropolitan area of Sydney, New South Wales, and another 300 children from the metropolitan area of Perth, Western Australia. Other psychometric properties of the ALNLRAC are yet to be investigated.

#### *3.10.4.1 Test procedure of the ALNLRAC*

The ALNLRAC is a 90 word reading test, which comprises 30 regularly-spelled words (hereafter referred to as 'regular words'), 30 irregularly spelled words (hereafter referred to as 'irregular words') and 30 non-words. The ALNLRAC was converted into a computer-administered format using Microsoft PowerPoint 2010 (Microsoft Corporation, 2010). Each word was presented on a single slide with a white background using Calibri font, size 96. The words were presented in random order.

During each trial, the child was presented with a written word and was required to read the word aloud. A standard set of instructions was given, "Please read the following words aloud. Some of the words might be familiar to you, while others have been made up by us. Are you ready?" The test took approximately 20 minutes to complete.

#### *3.10.4.2 Scoring of the ALNLRAC*

At the end of the test, a raw score was generated for each of the word types based on the number of correct items. The non-word reading raw score (ALNLRAC-NW-RS), the irregular word reading raw score (ALNLRAC-IW-RS), and the regular word reading raw score (ALNLRAC-RW-RS) were used in the data analysis.

### 3.10.5 Assessment of auditory sustained attention: Material and procedure

Auditory sustained attention was assessed with the !Score subtest of the Test of Everyday Attention for Children (TEA-Ch) (Manly, Robertson, Anderson, & Nimmo-Smith, 1999), a standardised test of attention. The task required the participants to actively maintain their attention when counting the number of sounds that were presented at random intervals across 10 test trials.

The !Score subtest was chosen because it is a continuous performance task. Continuous performance tests have been widely used in research and clinical practice as a measure of sustained attention and vigilance in various paediatric populations, including children with ADHD, learning disabilities, and reading disorders (Beale, Matthew, Oliver, & Corballis, 1987; Eliason & Richman, 1987; Gomes, Wolfson, & Halperin, 2007; Hagelthorn, Hiemenz, Pillion, & Mahone, 2003; McGee, Clark, & Symons, 2000; Tillery, Katz, & Keller, 2002). Additionally, it is a standardised test developed in Australia so it uses normative data that are based on Australian children (Manly et al., 1999). The TEA-Ch is routinely used in clinical settings and the !Score has been used in previous research in children with reading, language, and auditory processing deficits (e.g., McArthur et al., 2008). It has well-established psychometric properties that are reported in Manly et al. (1999).

##### *3.10.5.1 Test procedure of the TEA-Ch*

Testing commenced with two practice trials before the presentation of 10 test trials. During each trial, a sound that is likened to the scoring sound on computer games was presented repeatedly at random intervals. The child’s task was to count the number of sounds they heard ‘in their head’.

A standard instruction was given, “This task is all about counting. I am going to play you a recording from the computer and you have to count how many sounds you hear, as if you were keeping score by counting the number of scoring sounds in a computer game. The first sound you hear is just a signal to tell us when each game begins and ends. You don’t need to count these. At the end of each go, tell me how many you counted”. The test took 10 minutes to complete.

##### *3.10.5.2 Scoring of the TEA-Ch*

A raw score out of a maximum score of 10 was generated at the end of the test. This was used in the data analysis (i.e., the SCORE-RS).

#### 3.10.6 Assessment of Executive Control: Material and procedure

Executive control was assessed using an adaptation of the Simon Task (Simon & Ruddell, 1967), which was previously used in a study by Bialystok, Craik, and Luk (2008), hereafter referred to as the Simon Arrow Task (SAT). This task measures attention control and inhibition based on comparisons of reaction time data and errors obtained under different test conditions.

The SAT was chosen because of its non-verbal nature (Bialystok et al., 2008). As this is not a norm-referenced test, standardisation and other information on its psychometric properties were not available. The task was run on a computer using the DMDX software (Forster & Forster, 2003), which is a script-interpreting software for timing, screen control, and stimulus presentation used in cognitive experiments.

#### *3.10.6.1 Test procedure of the SAT*

The task involves an arrow being presented as the stimulus on the computer screen. The child responds to the stimulus by pressing one of two response keys as quickly and as accurately as possible. Three different test conditions were presented:

1) The control condition, where an arrow was presented in the middle of the screen and the child was asked to respond by pressing the left or right response key to indicate the direction in which the arrow was pointing.
2) The reverse condition, where the arrow was presented in the middle of the screen. The child was required to press the response key that corresponded to the direction *opposite to* the direction of the arrow. This condition was used to assess the ability to override a habitual response to a familiar stimulus, i.e., response inhibition.
3) The conflict condition, where the arrows were presented either on the left or right side of the screen, creating congruent trials when the direction and position of the arrow corresponded and incongruent trials when they conflicted, i.e., a right pointing arrow presented on the left side of the screen. As in the control condition, the child was asked to press the response key that corresponded to the direction that the arrow was pointing regardless of its position on the screen.

Each condition began with the standard instruction and five practice trials. This was then followed by the test trials. There were 24 trials in the control and the reverse conditions, and 48 trials in the conflict condition (24 congruent trials and 24 incongruent trials). Each condition was administered twice in a counterbalanced presentation order across the participants. The first order was: the control condition, the reverse condition, the conflict condition, the reverse condition, the conflict condition, and the control condition. The second order was: the control condition, the conflict condition, the reverse condition, the conflict condition, the reverse condition, and the control condition. The task took 15 to 20 minutes to complete.

#### *3.10.6.2 Scoring of the SAT*

Reaction time and error rate data were generated for each of the four types of trials[11]: 1) the control trials (SAT-CONT-RT and SAT-CONT-ER respectively), the reverse trials (SAT-REV-RT and SAT-REV-ER respectively), the conflict-congruent trials (SAT-CONGR-RT and SAT-CONGR-ER respectively) and the conflict-incongruent trials (SAT-INCONGR-RT and SAT-INCONGR-ER respectively). For the analyses, data from the two repeated conditions were collapsed. Hence, four mean reaction times and their SDs, and four mean error rates and their SDs were generated, one for each type of test condition (Control, Reverse, Congruent, and Incongruent). Incorrect responses, and those that were more than two SDs from the mean, were excluded from the analysis of the mean reaction times, according to the procedure published in Bialystok et al. (2008).

### 3.11 Data Analysis

Normality of the distribution of each dependent variable of the two groups was tested using the Shapiro-Wilk test. Non-significant results ($p > 0.05$) were found for all dependent variables which indicate that the data were normally distributed. Hence, the data analysis was conducted using parametric statistics.

[11] Two separate trials were included in the conflict condition, namely, the conflict-congruent trials and the conflict-incongruent trials.

The analysis was conducted using the two-tail, independent t-test to test for significant differences between the two groups on each of the following assessments: the CTOPP composite raw scores, the PPVT-RS, the TROG-RS, and the SCORE-RS. The two-way (Condition by Group) ANOVAs with repeated measures were used to compare the three word reading scores of the ALNLRAC of the two groups, as well as the mean reaction time and mean error rate of the control vs. the reverse conditions, and the conflict-congruent vs. the conflict-incongruent conditions of the SAT. The data analysis was conducted using IBM SPSS Statistics (2010).

# 4 STUDY 1: RESULTS AND DISCUSSION

## 4.1 Participant Characteristics

Between-group comparisons were conducted for age, nonverbal IQ (as measured by the RCPM, and FD ability (as measured by the SoundsPod) using the two-tail t-test. No significant differences were found for age ($t(14)= -0.57$, $p = 0.580$) and the nonverbal IQ standard score ($t(14)= 1-1.58$, $p = 0.135$). However, as tested, the FD-DIFF group had significantly poorer FD ability than the FD-WNL group ($t(14)= 6.30$, $p < 0.001$) (see Table 4.1 below).

**Table 4.1: Age, non-verbal intelligence (RCPM-SS) and FD ability (FD-SOUND-TS) of the FD-DIFF group and the FD-WNL group**

| | FD-DIFF | FD-WNL | SIG. TESTING |
|---|---|---|---|
| | Mean (SD) | Mean (SD) | p-value |
| **Age (months)** | 106.10 (9.42) | 109.47 (13.96) | 0.580 |
| **RCPM-SS** | 97.61 (13.33) | 107.19 (10.70) | 0.135 |
| **FD-SOUND-TS (Hz)** | 144.18 (54.29) | 18.23 (15.66) | < 0.001* |

Key: RCPM-SS = Standard Score of the Ravens Coloured Progressive Matrices; FD-SOUND-TS = FD Threshold Score of the SoundsPod. See Sections 3.9.3 and 3.9.4 for a description of these tests and their scoring.
*significance at $\alpha = 0.005$, two tailed *t*-test.

## 4.2 Results

The results of the between-group comparisons of the FD-DIFF and the FD-WNL groups will be presented in this chapter in regards to the following assessments: 1) PP ability; 2) word reading ability; 3) receptive language ability; 4) auditory sustained attention; and 5) executive control. This will then be followed by a discussion of the results.

### 4.2.1 Phonological processing ability

Summary data for the three composite raw scores of the CTOPP of the FD-WNL and the FD-DIFF groups are presented in Table 4.2. The two-tailed *t*-test for independent samples revealed that the FD-DIFF group showed significantly poorer phonological awareness (CTOPP-PA-CR) than the FD-WNL, $t(14) = -3.61$, $p = 0.003$. However, there were no significant differences between the two groups with respect to the mean composite raw score for phonological memory (CTOPP-PM-CR), $t(14) = -1.46$, $p = 0.167$, or the mean composite raw score for rapid naming (CTOPP-RA-CR), $t(14) = -0.55$, $p = 0.593$.

**Table 4.2: Summary data of the CTOPP-PA-CR, CTOPP-PM-CR, and CTOPP-RA-CR of the FD-WNL and FD-DIFF groups**

| **Measure** | **Group** | **n** | **Mean** | **SD** | ***p*** |
|---|---|---|---|---|---|
| **CTOPP-PA-CR** | FD-DIFF | 8 | 16.25 | 4.03 | 0.003* |
| | FD-WNL | 8 | 24.00 | 4.54 | |
| **CTOPP-PM-CR** | FD-DIFF | 8 | 18.12 | 3.40 | 0.167 |
| | FD-WNL | 8 | 21.50 | 5.61 | |
| **CTOPP-RA-CR** | FD-DIFF | 8 | 97.40 | 18.58 | 0.593 |
| | FD-WNL | 8 | 92.27 | 18.87 | |

KEY: CTOPP-PA-CR = Comprehensive Test of Phonological Processing Phonological Awareness Composite Raw Score; CTOPP-PM-CR = Comprehensive Test of Phonological Processing Phonological Memory Composite Raw Score; CTOPP-RA-CR = Comprehensive Test of Phonological Processing Rapid Naming Raw Composite Score
*significance at $\alpha = 0.005$, two tailed *t*-test.

### 4.2.2 Word Reading Ability

Summary data of the mean raw scores for non-word reading, irregular word reading, and regular word reading for the ALNLRAC (i.e. ALNLRAC-NW-RS, ALNLRAC-IW-RS, and ALNLRAC-RW-RS respectively) of the FD-WNL and the FD-DIFF groups are presented in Table 4.3.

A two-way ANOVA with repeated measures was conducted comparing the mean raw scores of the three different word types (i.e. non-word, irregular word, and regular word) between the FD-DIFF and the FD-WNL groups. The results show that there were significant differences between word types, $F(1, 14) = 27.86$, $p < 0.001$, and significant differences between the overall reading performance of the two groups, *F*(1, 14) = 6.61, *p* = 0.022. The interaction between word types and group was not significant, *F*(1, 14) = 2.84, *p* = 0.750.

Post-hoc pairwise comparisons using the two-tailed *t*-test showed that the FD-DIFF group demonstrated significantly poorer non-word reading and regular word reading abilities than the FD-WNL group (ALNLRAC-NW-RS: *t(*14) = -2.65, *p* = 0.019, and ALNLRAC-RW-RS: *t*(14) = -2.73, *p* = 0.016 respectively). However, there was no significant group difference for irregular word reading (ALNLRAC-IW-RS), *t*(14) = -1.49, *p* = 0.158.

**Table 4.3: Summary data of the ALNLRAC-NW-RS, ALNLRAC-IW-RS, and ALNLRAC-RW-RS of the FD-WNL and the FD-DIFF groups**

| **Measure** | **Group** | **n** | **Mean** | **SD** | **Post hoc comp. *p*-value** |
|---|---|---|---|---|---|
| **ALNLRAC-NW-RS** | FD-DIFF | 8 | 8.75 | 5.26 | 0.019* |
| | FD-WNL | 8 | 17.25 | 7.38 | |
| **ALNLRAC-IW-RS** | FD-DIFF | 8 | 12.88 | 5.67 | n.s. |
| | FD-WNL | 8 | 16.63 | 4.31 | |
| **ALNLRAC-RW-RS** | FD-DIFF | 8 | 16.75 | 7.01 | 0.016* |
| | FD-WNL | 8 | 24.38 | 3.66 | |

KEY: ALNLRAC-NW-RS = Assessment of Lexical and Non-lexical Reading Ability in Children Non-word Reading Raw Score; ALNLRAC-IW-RS = Assessment of Lexical and Non-lexical Reading Ability in Children Irregular Word Reading Raw Score; ALNLRAC-RW-RS = Assessment of Lexical and Non-lexical Reading Ability in Children Regular Word Reading Raw Score; Post hoc comp. *p*-value = Post hoc comparison *p*-value; and n.s. = non-significant

### 4.2.3 Receptive language ability

Summary raw score data for the PPVT-4 (PPVT-RS) and the TROG (TROG-RS) of the FD-WNL and FD-DIFF groups are presented in Table 4.4 below. The two-tailed *t*-test for independent samples revealed no significant differences in the mean PPVT-RS, *t(*14) = -0.86, *p* = 0.405, and the mean TROG-RS, *t(*14) = -1.71, *p* = 0.109 between the two groups.

**Table 4.4: Summary Data of the PPVT-RS and TROG-RS of the FD-WNL and the FD-DIFF groups**

| Measure | Group | n | Mean | SD | *p*-value |
|---|---|---|---|---|---|
| **PPVT-RS** | FD-DIFF | 8 | 134.63 | 15.34 | n.s. |
| | FD-WNL | 8 | 142.25 | 19.88 | |
| **TROG-RS** | FD-DIFF | 8 | 68.88 | 4.05 | n.s. |
| | FD-WNL | 8 | 72.88 | 5.22 | |

KEY: PPVT-RS = Peabody Picture Vocabulary Test Raw Score; TROG-RS = Test of Reception of Grammar Raw Score; and n.s. = non-significant

### 4.2.4 Auditory Sustained Attention

Summary raw score data for the !Score subtest of the Test of Everyday Attention for Children (SCORE-RS) of the FD-WNL and the FD-DIFF groups are presented in Table 4.5. The two-tailed *t*-test for independent samples revealed that there were no significant differences between the performance of the FD-DIFF and the FD-WNL groups on auditory sustained attention, $t(14) = -1.74$, $p = 0.104$.

**Table 4.5: Summary data for the SCORE-RS of the FD-WNL and the FD-DIFF groups**

| Measure | Group | n | Mean | SD | *p*-value |
|---|---|---|---|---|---|
| **SCORE-RS** | FD-DIFF | 8 | 5.38 | 2.67 | n.s. |
| | FD-WNL | 8 | 7.50 | 2.20 | |

KEY: SCORE-RS = Test of Everyday Attention for Children !Score Subtest Raw Score; n.s. = non-significant

### 4.2.5 Executive Control

Summary error rate and reaction time data of the different conditions of the SAT (i.e., control, reverse, conflict-congruent, and conflict-incongruent) (Bialystok et al., 2008) of the FD-WNL and FD-DIFF groups are presented in Table 4.6.

Two-way repeated measures ANOVAs were conducted comparing the **error rates** of the two groups across the control vs. the reverse conditions, and the conflict-congruent vs. the conflict-incongruent conditions. This revealed significant condition effects for both comparisons, $F(1, 14) = 7.50$, $p = 0.016$ (control vs. reverse) and $F(1, 14) = 22.67$, $p < 0.001$ (conflict-congruent vs.

conflict-incongruent), indicating that both groups had significantly more errors in the reverse condition and in the conflict-incongruent condition. However, although the FD-DIFF group made more errors overall, there were no significant group effects [$F(1, 14) = 0.36$, p = 0.560 (control vs. reverse), and $F(1, 14) = 2.62$, p = 0.128 (conflict-congruent vs. conflict-incongruent)], nor significant interaction effects [$F(1, 14) = 0.14$, p = 0.713 (control vs. reverse), and $F(1, 14) = 0.01$, p = 0.913 (conflict-congruent vs. conflict-incongruent)]. The findings indicate that both groups made significantly more errors in the reverse condition as compared to the control condition and there was no significant difference between the two groups. Similarly, they also showed significantly more errors in the conflict-incongruent condition as compared to the conflict-congruent condition. Again, there was no significant difference between the two groups.

**Table 4.6: Summary data for the mean error rate and mean reaction time of the four SAT conditions of the FD-WNL and the FD-DIFF groups**

| Measures | Groups | n | Mean ER (SD) | Mean RT (SD) |
|---|---|---|---|---|
| **SAT-CONT** | FD-DIFF | 8 | 3.13 (2.47) | 622.83 (220.96) |
| | FD-WNL | 8 | 1.75 (1.28) | 532.96 (139.07) |
| **SAT-REV** | FD-DIFF | 8 | 5.88 (5.54) | 723.30 (216.50) |
| | FD-WNL | 8 | 5.38 (4.75) | 615.03 (119.43) |
| **SAT-CONGR** | FD-DIFF | 8 | 4 (3.42) | 764.19 (220.48) |
| | FD-WNL | 8 | 1.88 (1.55) | 598.89 (105.53) |
| **SAT-INCONGR** | FD-DIFF | 8 | 6.75 (3.54) | 790.44 (219.33) |
| | FD-WNL | 8 | 4.50 (2.78) | 642.49 (103.56) |

KEY: ER = Error rates; RT = Reaction time; SAT-CONT = the control trials; SAT-REV = the reverse trials; SAT-CONGR = the conflict-congruent trials; SAT-INCONGR-RT = the conflict-incongruent trials

Two-way repeated measures ANOVAs were also conducted comparing the mean **reaction time** of the two groups across the control condition vs. the reverse condition, and the conflict-congruent condition vs. the conflict-incongruent condition. There were significant differences for condition (Control vs. Reverse) [$F(1, 14) = 28.35$, $p < 0.001$]; however, there was no significant group difference [$F(1, 14) = 1.26$, $p = 0.280$] i.e., both groups were similar in that they demonstrated significantly slower reaction time. There was no significant interaction [$F(1, 14) = 0.288$, p = 0.600].

With regard to the comparisons between the reaction time of the conflict-congruent condition vs. conflict-incongruent condition of the two groups, there was a significant condition effect, $F(1,14) = 2.12$, p = 0.004, and the group effect was trending towards a significant difference, $F(1, 14) = 0.4.30$, p = 0.057. However, there was no significant interaction, $F(1,14) = 0.43$, p = 0.523. These findings suggest that both groups showed significantly slower reaction time in the conflict-incongruent condition as compared to the conflict-congruent condition. The group effect that was trending towards a significant difference might be a partial indication that poorer FD co-exists with slower reaction time in the conflict-incongruent condition. However, such a conclusion remains tentative.

## 4.3 Discussion

The results of STUDY 1 showed that the mean scores of the FD-DIFF group were lower than those of the FD-WNL group across all measures (i.e., phonological awareness, phonological memory, rapid naming, non-word reading, regular word reading, irregular word reading, receptive vocabulary, sentence comprehension, auditory-sustained attention and executive control). However, not all measures showed a significant group difference. The FD-DIFF group showed significantly poorer performance on phonological awareness, non-word reading, and regular word reading. Nevertheless, there were no significant differences between the two groups on the other measures, i.e., measures of phonological memory, rapid naming ability, irregular word reading, receptive grammar, receptive vocabulary, auditory sustained attention, and executive control.

### 4.3.1 FD, word reading, and phonological processing

The notion that poor FD performance co-exists with poor reading ability has been well established in the literature (e.g., Ahissar et al., 2000; Baldeweg et al., 1999; De Weirdt, 1988;

Halliday & Bishop, 2006; McAnally & Stein, 1996; McArthur & Bishop, 2004; Talcott et al., 2002). Studies have demonstrated that children with SRD often show significantly poorer FD ability than age-appropriate readers (Baldeweg et al., 1999; De Weirdt, 1988; Halliday & Bishop, 2006; McAnally & Stein, 1996). Additionally, others have found a relationship between FD and reading ability in unselected cohorts of adults and children (Ahissar et al., 2000; Talcott et al., 2002). To date, research of FD difficulties in children who have an explicit/ reported diagnosis of APD is sparse. To the best of this author's knowledge, the present study might be one of the first in this area. Most studies that have investigated the association between FD and reading ability were conducted in the SRD population.

The results of the present study extend previous research showing that poor(er) FD is associated with difficulties with some aspects of reading but not others. Coltheart et al. (1993) proposed that the reading of an alphabetic script might involve two processes, namely: 1) the 'lexical process', also referred to as the 'word-level sight vocabulary' process, which involves the reading of whole words by directly accessing the mental representation of the written word in the Orthographic Input Lexicon (i.e., a system of word specific orthographic representations) and the subsequent retrieval of its phonological form from the Phonological Output Lexicon; and 2) the 'non-lexical process', also referred to as the 'sub-word level phonetic decoding' process or simply 'reading by decoding', which involves breaking the word down into its constituent phonemes and decoding the letter-sound segments within a word. The latter process is also referred to as 'letter to sound mapping' (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Zeigler, 2001; Wolf & Bowers, 1999). These two reading processes are represented in the Dual Route Cascade (DRC) Model for visual word recognition and reading aloud (Coltheart et al., 2001).

Figure 4.1 represents DRC model adapted from Coltheart et al. (2001), in which written words lead to the activation of the relevant mental representation of the letters in the Letter Unit according to their visual features. Subsequently, words are either analysed as a whole word through the Lexical Route (highlighted in red in Figure 4.1) or read by applying letter-sound rules via the

Non-Lexical Route (highlighted in blue in Figure 4.1). The activation of either process depends on the type of word and the reader's familiarity with the word.

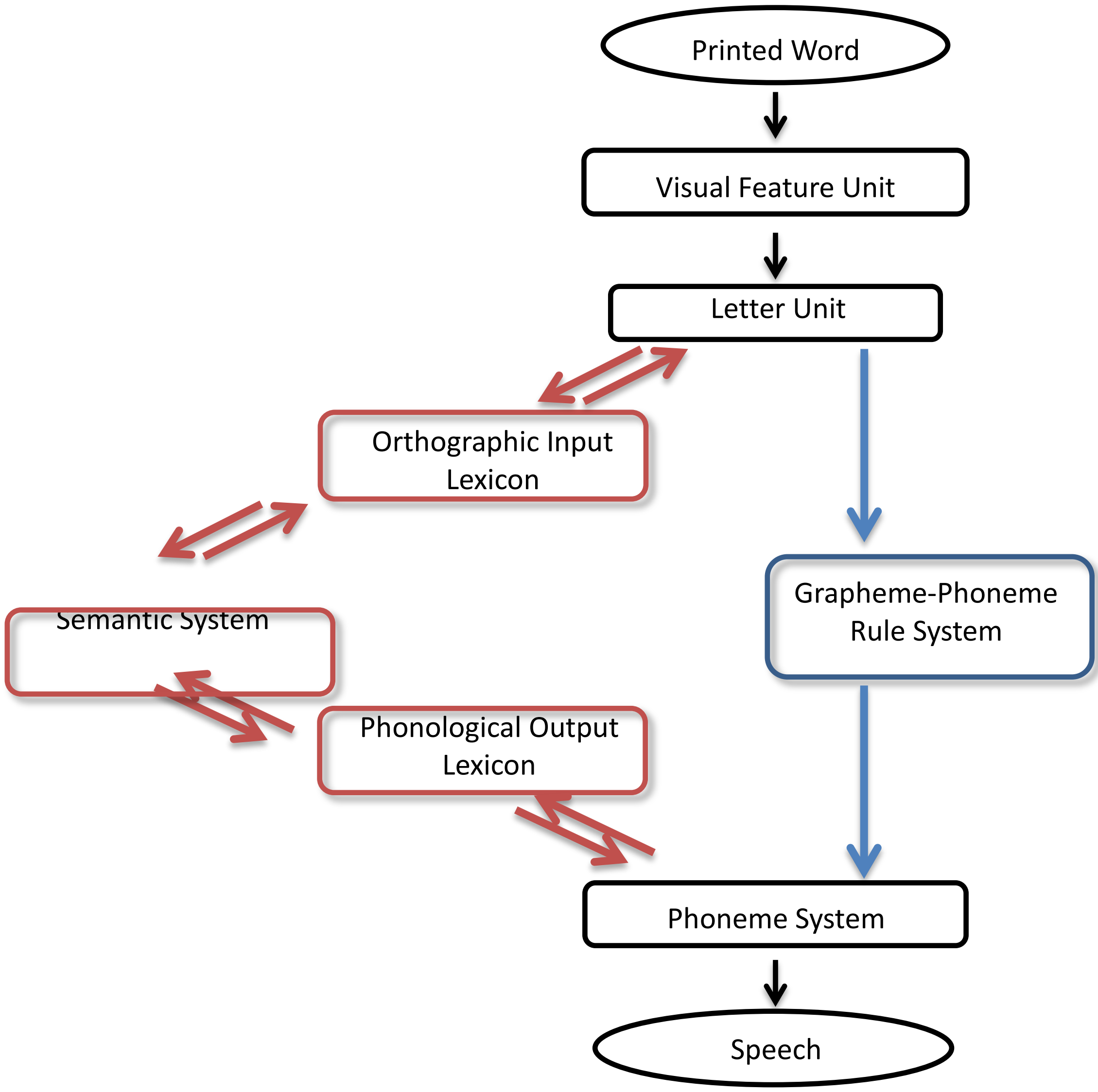



**Figure 4.1: An illustration of the Dual Route Cascade (DRC) Model for visual word recognition and reading aloud adapted from Coltheart et al. (2001). The lexical reading route is highlighted in red and the non-lexical route is highlighted in blue.**

For instance, irregular words (i.e., words that do not follow the letter-sound rules of English) cannot be decoded and processed using the Non-Lexical Route, because (individual) letter to sound mapping would lead to an incorrect pronunciation of the word. Irregular words can only be read via the Lexical Route. On the other hand, non-words can only be read via the Non-Lexical Route, because they have no meaning, and therefore, cannot be read using the Lexical Route which accesses the semantic system. Words that are regularly spelt (i.e., the regular words) can be read via either the Lexical or Non-Lexical Route depending on the familiarity of the word to the individual reader[12].

Therefore, attempts to read irregular words result in the activation of the Lexical Route where the corresponding mental representation of the whole word in the Orthographic Input Lexicon is activated, which subsequently leads to the activation of its corresponding representation in the Semantic System and the Phonological Output Lexicon. This, in turn, activates the relevant phonemes in the Phoneme System and results in the verbal output of the word. However, non-words will activate the Non-Lexical Route where the letter string is converted to a phoneme string using grapheme-phoneme correspondence rules in the Grapheme-Phoneme Rule System. Subsequently, the relevant phonemes are activated in the Phoneme System and the verbal output of the word is produced. According to the current findings, poor(er) FD seems to affect the non-lexical route of reading more than the lexical route. The FD-DIFF group showed significantly poorer non-word and regular word reading than the FD-WNL group, but there were no group differences in the ability to read irregular words. This shows that the FD-DIFF group had more difficulty with non-lexical reading than with lexical reading relative to their FD-WNL peers.

Evidence that poor(er) FD affects the non-lexical reading process more than the lexical reading process is also consistent with the pattern of results observed related to phonological processing. The results of the present study showed that FD difficulties co-existed with poorer phonological awareness but not rapid naming (also known as ‘rapid automatic naming’ - RAN), or phonological memory. There is consensus in the literature that phonological processing comprises three *different* facets: 1) phonological awareness; 2) RAN; and 3) phonological memory (Ramus & Szenkovits, 2008; Wagner & Torgesen, 1987; Wagner et al., 1999). Ramus and Szenkovits (2008) stated that phonological awareness, RAN, and phonological memory could be considered as the

[12] When a proficient reader encounters a new regular word for the first time, he/she would have to employ the Non-Lexical Route to “sound out” or to decode the word. After the word has been learnt, and depending on familiarity and frequency of exposure, the reader might read the word as a whole using the Lexical Route.

'dyslexia triads'. They observed that the poor performance of people with dyslexia on most, if not all, verbal tasks can be explained by one or several of these processes. All of these processes implicate phonological representation[13] but in their own separate ways.

Ramus and Szenkovits (2008) suggested that phonological awareness is concerned with the conscious access and attention to, and the manipulation of the '**sublexical phonological representations**' (i.e., the mental representation of sounds verses the mental representation of sound combinations that form words; Ramus referred to the latter as '**lexical phonological representations**') which occur prior to, and could occur independent of, lexical access. This proposition is consistent with the earlier works of Wagner et al. (1999), and Wolf and Bowers (1999) who suggested that phonological awareness is important for the decoding of letter-sounds and the use of grapheme-phoneme correspondence rules. Therefore, the finding of the present study that FD affects non-word and regular word reading, as well as phonological awareness is consistent with the postulation of these authors that phonological awareness is mostly associated with non-lexical reading. The present finding is also consistent with previous studies that have demonstrated an association between FD and phonological awareness difficulties. Talcott et al. (2002) and Talcott, Witton, and McLean (2000) reported that FD is a robust predictor of children's phonological skills as measured by phonological awareness tasks, such as assessing children's ability to manipulate phonemes in spoken words.

RAN measures the speed at which an individual can rapidly name familiar visual symbols or language stimuli, e.g., colours, simple objects, numbers, or letters (Wolf & Bowers, 2000). RAN is concerned with the efficiency of retrieving **lexical phonological representations** from the long-

[13] A phonological representation is the mental representation of the sounds and combinations of sounds that form the words of a spoken language (Goswami, 2000; Goswami, 2002). It is widely recognised that there is more to phonology that goes beyond phonological awareness, phonological memory, and rapid naming. There is a large body of research investigating the "quality" of the phonological representations and the hypothesis that dyslexia might be a result of **degraded** phonological representations. Researchers have proposed that the phonological representations in dyslexia could be fuzzy, noisy, or underspecified. Some have described a deficit in phonological representations as the representations having a lower resolution, a larger than typical grain size, or that they are not sufficiently categorical, so on and so forth. A discussion regarding the deficits related to phonological representations goes beyond the scope of this thesis and more information can be found in Ramus (2001).

term memory (Ramus & Szenkovits, 2008). The DRC Model (Figure 4.1) proposed that word retrieval is part of lexical reading, i.e., the direct retrieval of the mental representation of the whole word from the Semantic System and the Phonological Output Lexicon. However, beyond what is represented in the DRC model, RAN involves a complex group of processes that go well beyond the phonological system (Wolf & Bowers, 1999). According to Wolf and Bowers (2000), RAN also demands an array of attentional, perceptual, conceptual, memory, lexical, and articulatory processes. The findings of the present study showed that RAN is less affected by difficulties in FD than phonological awareness. It could well be that FD has a lesser effect on RAN because FD only affects the processing within the phonological system, whereas RAN also relies on the additional cognitive processes mentioned above. The current set of data does not allow for further elaboration on this matter. Future research could consider exploring the possible reasons of how FD contributes to reading and its relationship with phonological awareness and RAN.

Finally phonological memory refers to the capacity of the short-term memory to store phonological representations during processing (Ramus & Szenkovits, 2008; Wagner et al., 1999). This temporary storage of information is considered to play an important role in reading and reading acquisition (Gathercole & Baddeley, 1990). In letter to sound conversion, one has to keep track of earlier sounds that have already been converted from their orthographic form before being able to say the whole word. Previously, researchers proposed that poor FD might be a result of a short-term memory deficit, i.e., impairment in phonological working memory (Ahissar, 2007; Ahissar et al., 2006; Banai & Ahissar, 2004, 2010). For instance, Ahissar and colleagues suggested that FD deficits are by-and-large due to difficulties in storing, and subsequently, accessing stimulus-specific short-term memory representations (see Section 2.3.2.2). During a trial of the FD task, the individual would need to store all the tones that were presented in the working memory before they could compare and identify the target tone. This is known as the perceptual anchor hypothesis. Based on the perceptual anchor hypothesis, one would predict that the FD-DIFF group would demonstrate significantly poorer phonological memory. The results of the present study did not support this hypothesis in that there was no significant difference in phonological memory between the FD-DIFF and the FD-WNL group.

In summary, the current findings regarding word reading and phonological awareness support previous research, showing that a relationship between FD, phonological awareness and reading exists. Additionally, FD appears to affect the non-lexical reading process more than the lexical reading process.

### 4.3.2 FD and language

The results of the present study showed that there were no significant differences between the FD-DIFF group and the FD-WNL group in terms of their mean language scores. Again, there is limited research of FD difficulties in children who have an explicit/ reported diagnosis of APD. Most research regarding FD and language investigated FD ability in individuals with SLI. These studies have demonstrated that FD difficulty could co-occur with language difficulty, which seems to contradict the present finding. For instance, previous studies have reported poor FD in children with SLI as such that children with SLI were found to have significantly poorer FD compared to children with age-typical language ability (Hill et al., 2005; McArthur & Bishop, 2004; Mengler et al., 2005).

One possible explanation for the inconsistency between the findings of the present study and those of previous research might be the difference in sampling. Previous studies had specifically sampled children with SLI but the present study has recruited children with APD regardless of whether they had a positive SLI diagnosis or not. Only two children in the current sample showed language ability consistent with the criteria for a positive SLI diagnosis based on the criteria listed in Bishop (2006) (see Section 3.5.3 for more details). The number of children with signs of SLI was equivalent amongst the two groups, one was in the FD-WNL group and the other one was in the FD-DIFF group. This could have led to the overall non-significant group difference in the language scores. Therefore, the result of the present study does not support the notion that FD affects language, if so, there would have been more children with SLI in the FD-DIFF group. However, this conclusion remains tentative due to the small sample size. Future studies could consider sampling a large, unselected cohort of children to determine the correlation between FD and language ability. This approach had been employed by Moore et al. (2010) to explore the potential relationship that FD and other AP abilities might have with cognitive abilities of non-verbal intelligence, working memory, and reading. 1469 children participated in that study. They found weak correlations between FD and non-verbal intelligence, working memory, and reading. A similar approach could be used to determine whether FD is associated with language abilities.

### 4.3.3 FD and auditory sustained attention

No significant differences were found between the FD-DIFF group and the FD-WNL group with regards to their performance on the auditory sustained attention test, the !Score subtest of the TEA-Ch. Again, there is limited research of FD difficulties in children who have an explicit/ reported diagnosis of APD. However, some studies have investigated FD and attention in children with SLI and SRD, and in unselected cohorts (Halliday et al., 2008; McArthur & Bishop, 2004; McArthur et al., 2008; Moore et al., 2008; Moore et al., 2010; Sutcliffe et al., 2006; Sutcliffe, 2006).

The present finding is consistent with the findings of two studies that investigated the co-morbidity of poor FD and attention difficulty using the !Score in children with SLI (McArthur & Bishop, 2004; McArthur et al., 2008). McArthur and Bishop (2004) compared the performance on the !Score between three groups of children: 1) children with SLI and poor FD (n = 5); 2) children with SLI but age-appropriate FD (n = 11); and 3) children with age-appropriate language ability (n = 16). McArthur et al. also incorporated another subtest from the TEA-Ch that measured attention control. They found that there were no significant differences between the mean !Score and attention control scores between the three groups.

McArthur et al. (2008) investigated the change in performance on the !Score pre – post FD intervention in 16 children with poor FD and comorbid SRD or SLI. Their findings showed that there was no significant difference in the performance on the !Score pre – post FD intervention, despite significant improvement in FD performance. They concluded that the improvement in FD was specific to FD and not due to improved attention. Therefore, the findings of the above studies, along with the present one, suggest that FD performance is unrelated to auditory sustained attention. However, this finding seems contradictory to the findings of other studies which found that poor attention contributes to poor performance on FD tasks (Halliday et al., 2008; Moore et al., 2008; Moore et al., 2010).

A possible explanation for the discrepancy in findings between these two groups of studies (i.e., McArthur & Bishop (2004), McArthur et al. (2008), and the present study showing that FD is unaffected by attention, verses those of Halliday et al. (2008), Moore et al. (2008), and Moore et al. (2010) who have reported that FD is affected by attention) might lie in the methodology for how attention was measured. In Halliday et al. (2008), Moore et al. (2008), and Moore et al. (2010), attention was measured based on an analysis of the pattern of response within the FD task. Halliday et al. (2008) used *lapse rate* within the FD task as a measure of change in attention[14]. Moore et al. (2008) and Moore et al. (2010) used the variability within the FD task as a measure of attention. These researchers proposed that inattention would lead to greater variability in performance which would manifest as higher thresholds, a greater number of reversals in response adjustment, and that the individual might demonstrate greater performance differences between different runs of the FD task. Moore et al. (2008) used ‘inter-track threshold difference’ (i.e., the percentage of frequency differences between the threshold score obtained from two runs of the task) as a measure of response variability. They found that **most** children with poor FD performance demonstrated large inter-track threshold differences. These children typically showed good discrimination on the first

[14] Lapse time refers to the “extent to which an individual would fail to reach 100% correct at the highest frequency difference (between the target tone and the standard tone) in any given run (of the FD task)” (p. 4395; note: author’s parentheses).

few trials of the task which showed that they understood the task demands and were able to discriminate between the tones. However, as the task continued, their performance seemed to deteriorate and the children began to make discrimination errors even at levels at which they had discriminated correctly before. Therefore, the researchers concluded that this variability in FD was not due to a difficulty in discriminating the frequency of acoustic signals but rather, a difficulty in sustaining attention.

Moore et al. (2010) compared the FD performance and attention in a group of 6-11 year-old children (N = 1,469) recruited from the general public. They found that approximately 95% of children who demonstrated poor FD threshold scores also showed larger response variability, which the researchers suggested was indicative of inattention. The manner in which response variability was computed was not clearly stated, although it was mentioned that the response variability index was derived from “the number and level of trials in each adaptive step, from the number and width of adaptive stair-case reversals, and from inter-track difference measures” (pp. S12). However, the specific formula was not provided. Moore et al. also included another test of attention, the IHR Cued Attention Test (Riley, Ferguson, Ratib, & Moore, 2009), which measured phasic attention/alertness, which is “the ability to increase response readiness for a short period of time subsequent to external cues or stimuli” (Sturm & Willmes, 2001, pp. S76). Phasic attention was measured by comparing the difference in reaction time between trials where the target stimulus was preceded by a cue, and those where the target stimulus was not preceded by a cue. The rationale of the test is that the reaction time to response to a simple auditory or visual stimulus decreases when the stimulus is preceded by a cue. This would vary inversely with attention, such that an inattentive individual should benefit more from the cue than an alert individual. Therefore, there would be a greater difference between the cued and the uncued reaction times in the inattentive individual. The test was conducted in both the auditory modality and the visual modality. The findings of this study showed that auditory phasic alertness was unrelated to poor FD. This contradicts with the notion that poor auditory attention causes poor FD. Interestingly, significantly correlation was found between *visual phasic alertness* and the FD threshold score.

What remains unclear to date is whether response variability is a valid indication of the effect of auditory attention in FD performance. There seems to be some theoretical grounds for this (see Moore et al., 2010 for details), but this assumption has not been formally tested. The finding that poor FD threshold score correlated with high response variability, and not to other auditory attention measures, challenges this assumption. If high response variability is indicative of inattention in the auditory modality, then there should have been evidence of an association between FD performance and other measures of auditory attention. However, it could be that response variability reflects some other constructs of the auditory attention that have not yet been tested. It could also be that FD is more affected by visual phasic attention, rather than sustained auditory attention. Nevertheless, this conclusion remains tentative and needs to be formally tested. Future studies could consider comparing the performance on sustained auditory attention and visual phasic alertness measures in children with and without FD difficulty. Studies of this kind will provide more insight on how attention affects FD and other AP abilities.

Sutcliffe et al. (2006) and Sutcliffe (2006) used yet another approach to investigate FD and attention. Sutcliffe et al. (2006) investigated changes in FD performance in children with ADHD when their attention state was altered with stimulant medication. Eighteen children with ADHD and 18 age-matched controls participated in the study (age 6-12 years). Their findings showed that children with ADHD had significantly poorer FD performance than controls, either with the stimulant medicine or without it. Their FD performance was even poorer and more variable when they were off the stimulant medicine compared to when they were on the medicine. Similarly, Sutcliffe (2006) published a case study detailing significant improvement in FD performance in a child with ADHD who was on stimulant medicine.

The finding that children with ADHD often demonstrating poor FD threshold scores and high response variability, and that marked FD improvement was observed after children were on stimulant medicine, seems to support the notion that performance on FD tasks can be affected by attention. What remains unclear is whether FD is more affected by attention in the auditory modality or the visual modality. It seems plausible that stimulant medicine might have an effect in improving visual processing and visual phasic attention which, in turn, resulted in improved FD performance. In view of the potential influence that visual processing and visual attention might have on FD, the construct validity of psychoacoustic FD tasks needs to be investigated. Further research could consider exploring whether psychoacoustic FD tasks are a valid measure of the ability to differentiate frequency differences in acoustic signals, or that they are confounded by limitations in the visual modality.

In summary, the results of the present study suggest that the difference in FD in the present sample were not due to auditory-sustained attention. Further research is needed to explore the influence of attention on FD tasks. Studies could consider formally testing the assumption that response variability is a valid measure of attention on FD performance. Additionally, the potential influence of visual processing and visual attention on the performance of psychoacoustic FD tasks needs to be explored.

#### 4.3.4 FD and executive control

The findings of the present study were inconclusive about the effects of executive control on FD. Executive control is a term used for the management, regulation, and control of the cognitive processes of working memory, reasoning, task flexibility, problem solving, planning, and execution (Elliott, 2003; Monsell, 2003). It refers broadly to those cognitive abilities that are associated with, or subserved by, the prefrontal cortex and the interconnected subcortical system (Diamond, 2001; Elliott, 2003; Stuss, 1992). The results of the present study show that children with poor FD demonstrated slower reaction times across all experimental conditions of the SAT. However, no comparison reached the level of statistical significance.

A possible explanation for this non-significant result might be that the FD task used in the present study was an ‘untimed’ task. So, the present measure of FD ability (i.e. the FD threshold score) did not take into account the time that was needed for the participant to respond during each trial, i.e., the reaction time. The mean reaction time of the FD task might be a more meaningful comparison given that the present executive control measure is based on reaction time. The group effect of the reaction time on the conflict-incongruent trials was trending towards a significant difference, suggesting that this matter might warrant further investigation. Future studies could consider measuring the reaction time during the FD task and comparing this with performance on the SAT.

In summary, the results of the present study confirm previous reports that FD difficulties often co-exist with reading difficulties. Extending the previous findings, the present results demonstrate that FD mainly affects the non-lexical reading process but has minimal impact on the lexical reading process. These results do not provide evidence that FD affects language ability within the sample studied, or the potential influence that attention and executive control might have on FD. More importantly, the question of whether targeting FD as a specific remedial goal in children with poor FD would bring added benefits in the remediation of comorbid reading difficulties warrants further investigation. This was the research focus of STUDY 2.

# 5 STUDY 2: METHODOLOGY

## 5.1 Aims of STUDY 2

The aim of this study was to investigate the outcomes of two intervention programs, when administered in isolation or in combination, in children with FD and PP difficulties, who were also diagnosed with APD. The interventions were: 1) a computer-based training program to improve FD, the SoundsPod (McArthur et al., 2008), referred to as the 'FD intervention', and 2) a computer-based intervention program to improve phonological processing, the ReadingDoctor (Rajkowski, 2003), referred to as the 'PP intervention'. An important focus of this study was to investigate whether prior FD intervention would enhance the outcome of the subsequent PP intervention.

The intervention-specific effect of these two interventions and the maintenance of the intervention-specific effect were explored. Generalisation of the potential intervention effects of both programs was also studied. For the FD intervention, this was measured in terms of generalisation to a different, yet equivalent task of FD, the 'Dinosaur Task' (Sutcliffe & Bishop, 2005). For the PP intervention, this was measured in terms of generalisation to a measure of phonological awareness, the Phonological Awareness Composite Score of the CTOPP (CTOPP-PA-CS). Additionally, the generalisation of the FD intervention and the PP intervention to other cognitive abilities was also explored. These other cognitive abilities were word reading, receptive vocabulary, and receptive grammar. Finally, the effect that prior FD intervention had on the PP intervention outcomes was also investigated.

## 5.2 Specific Research Questions

The specific research questions for STUDY 2 are set out below:

**A. Intervention-Specific Effect of the FD Intervention and Maintenance Effect**

1. *Intervention-Specific Effect*: Does FD intervention result in improved FD ability that is specific to the FD intervention rather than to the intensive exposure to a computer program?
2. *Maintenance of the Intervention-Specific Effect*: Is the intervention-specific effect of the FD intervention maintained after six weeks?

**B. Intervention-Specific Effect of PP Intervention and Maintenance Effect**

1. *Intervention-Specific Effect*: Does the PP intervention result in improved PP ability?
2. *Maintenance of the Intervention-Specific Effect*: Is the intervention-specific effect of the PP intervention maintained after six weeks?

**C. Generalisation of FD and PP Intervention Effects**

1. *Within-task generalisation of the FD and PP Intervention*: Does the potential improvement in FD or PP ability achieved during the intervention programs generalise to FD or PP ability measured by another test of FD or PP?
2. *Generalisation effects of FD and PP Intervention to reading and language*:
   a. Do the effects of the FD intervention and the PP intervention generalise to word reading ability?
   b. Do the effects of the FD intervention and the PP intervention generalise to receptive language?

**D. The Effects that prior FD Intervention have on PP Intervention outcomes**

1. Are the potential effects of the PP intervention greater with prior FD intervention, in terms of:
   a. The PP intervention-specific effect;
   b. The within-task generalisation; and
   c. The generalisation of the PP intervention effects to word reading and language ability?

2. Are the potential effects of prior FD intervention specific to the FD intervention, or are they related to prior exposure to a computer intervention program in general?

## 5.3 Study Design

STUDY 2 was a RCT aimed at investigating the effectiveness of interventions for APD. Participants with FD difficulties, who were also found to have PP difficulties, were randomly assigned to one of four experimental groups. These were: 1) one group that received both FD intervention and PP intervention (i.e., the FD-PP group); 2) one group that received a visual discrimination intervention, which was a visual analogue to the FD intervention, followed by PP intervention (i.e., the VD-PP group); 3) one group that received PP intervention on its own (i.e., the PP group); and 4) a control group that did not receive any intervention for the duration of the study (i.e., the CON group) (see Figure 5.1). Details of each of the intervention programs will be provided in Section 5.7 of the current chapter.

This study was divided into three phases, each lasting six weeks: Phase 1, Phase 2, and the Maintenance Phase. During Phase 1, the FD-PP group received six weeks of FD intervention, and the VD-PP group received six weeks of VD intervention. The PP group and the CON group received no intervention for six weeks during Phase 1. All four groups were assessed before the start of the study and reassessed at the end of Phase 1 (i.e., at Ax2). During Phase 2, the FD-PP, VD-PP, and PP groups all received PP intervention for six weeks, while the CON group received no intervention. All four groups were reassessed at the end of Phase 2 (i.e., at Ax3). Finally, during the Maintenance Phase, none of the four groups received any intervention, and were assessed for the last time after six weeks (i.e., at Ax4). For ethical reasons, the CON group was provided with a copy of, and access to, the PP intervention at the end of the study (after maintenance).

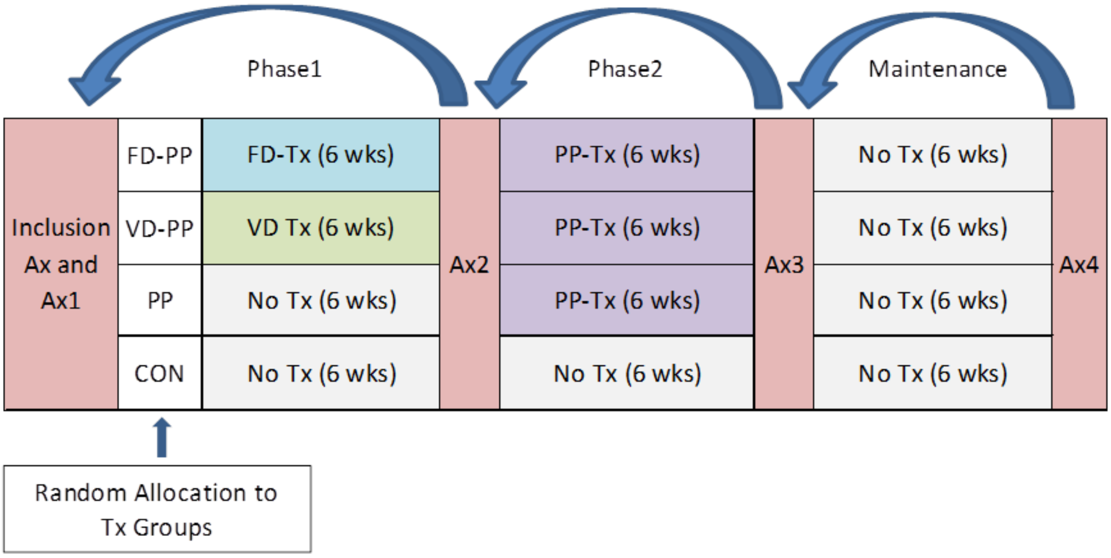



**Figure 5.1: Study design of Study 2. A RCT where the participants were randomly assigned to the four experimental groups: the FD-PP group, the VD-PP group, the PP group, and the CON group. The study consisted of three phases: Phase 1, Phase 2, and the Maintenance Phase**

KEYS: Inclusion Ax = Inclusion Assessment; Ax1 = Assessment 1; Ax2 = Assessment 2; Ax3 = Assessment 3; Ax4 = Assessment 4; FD-Tx = FD Intervention; VD-Tx = VD Intervention; PP-Tx = PP Intervention; No-Tx = No intervention

## 5.4 Participants

Twenty-one children, aged between 7;5 years and 9;9 years (mean = 8;5 years, and SD = 0.70), met the inclusion criteria for Study 2.

### 5.4.1 Inclusion criteria

The inclusion criteria were that the participating child must:

- show FD difficulty for age based on the normative data from McArthur et al. (2008), i.e., the child would require a larger frequency difference between the target tone and the standard tone than other children of the same age to discriminate the two tones;
- show PP difficulties. This was defined by a score below the first SD of the mean score for age on one or more subtests in the CTOPP.

One participant was excluded from the study as the family had difficulty complying with the intervention regimen. One participant in the FD-PP group was lost to follow-up after Ax2 due to other family commitments; hence, data were collected for this participant on Ax1 and Ax2 but not for Ax3 and Ax4. Therefore, there were five participants in the FD-PP group in Ax1 and Ax2, with four remaining in Ax3 and Ax4; six participants in the VD-PP group; four participants in the PP group, and five participants in the CON group. Additionally, one child in the FD-PP group had a reported diagnosis of ADHD. The family was asked to withhold the ADHD medication prior to the assessment sessions, so that the effect of the medication would not confound the test results.

## 5.5 Randomisation

### 5.5.1 Sequence generation

The participants were randomly assigned to one of the four experimental conditions using a randomisation list. The list was generated based on the randomisation algorithm of Random Sorting using a maximum allowable percentage deviation of 12%. The Power Analysis and Sample Size 2008 software (Hintze, 2008) was used to generate this sequence.

### 5.5.2 Allocation concealment mechanism

The allocation sequence was concealed from the researcher who was assigning the participants into groups. The experimental condition was written on the inner side of a folded card and placed in sequentially numbered, opaque, sealed envelopes. To prevent subversion of the allocation sequence, the envelopes were opened after the child was enrolled into the study at the completion of all baseline assessments at Ax1.

## 5.6 Procedure

Every participant who satisfied the inclusion criteria for Study 2 was randomly assigned to one of the four groups at the end of Ax1, namely 1) the FD-PP group; 2) the VD-PP group; 3) the PP group; or 4) the CON group. The participants in the different groups underwent different intervention regimes, with the exception of those in the control (CON) group who did not receive any intervention during the study.

Three different interventions were included in this study, i.e., the FD intervention, the VD intervention, and the PP intervention. The intervention schedule remained consistent across all three interventions. The intention was that the participants be engaged in the different interventions for 20 minutes per day, four days per week for six weeks.

During Phase 1 (see Figure 5.1), the participants in the FD-PP and VD-PP groups were instructed to play the ‘game’ (i.e., the FD intervention or the VD intervention task) five times during each session, which was estimated to take approximately 20 minutes. The intervention schedule was based on the procedure in McArthur et al.’s (2008) original study. The PP and CON groups received no intervention during this phase.

In Phase 2, the participants in the FD-PP, VD-PP, and PP groups all undertook the PP intervention for 20 minutes a day, four days per week, for six weeks, whereas the participants in the CON group continued another six weeks of no intervention. Phase 2 was followed by the Maintenance Phase, which was a six-week period in which no intervention was provided for any group.

All participants were assessed before the start of the intervention and were reassessed after each phase, with the final assessment being after the six week maintenance period. Each assessment session was approximately two and a half hours in duration, with the exception of the first assessment (Ax1), which lasted approximately three to three and a half hours, including appropriate breaks as needed.

## 5.7 The Intervention Programs

### 5.7.1 Frequency discrimination intervention (the SoundsPod)

The FD intervention was identical to the intervention program used in McArthur's 2008 study. It was developed by Rob Seiler from ELR Software Pty Ltd. The same task was also used in the assessment sessions as a measure of the intervention-specific effects associated with the FD intervention (see Section 3.9.4 for details of the test version of this task). The FD intervention was uploaded to a shared folder in Dropbox (Houston & Arash, 2007), a cloud solution whereby data can be stored in cyber-space. The participants accessed the FD intervention from their home computer via the shared folder. Performance data, such as the date, time and duration of access, the type of training that the participant engaged in, the training targets, and the participant's response in each trial were all recorded automatically by the software program. This was updated in the shared folder as each participant engaged in the intervention. The researcher monitored the performance data to identify issues related to compliance to the intervention schedule. Families were contacted when any issues arose. Information on the amount of FD intervention received by the FD-PP group can be found in Section 6.2.

The intervention version of the FD task comprised five stages. Each child moved through the stages depending on the threshold score they achieved. If they passed Stage 1, they moved on to Stage 2, and if they failed Stage 2, they moved back to Stage 1. A child would pass Stage 1 if their threshold score was better than 300Hz (i.e., they could detect a frequency difference between the target and the standard tone that was 300Hz or less apart). Likewise, they would pass Stage 2 if their threshold score was better than 200Hz. Similarly, they would pass Stages 3, 4, and 5, if their threshold score was better than 100Hz, 50Hz, and 20Hz respectively. Each intervention session began at Stage 1. Each child was instructed to play the game five times and aimed to reach the highest possible stage.

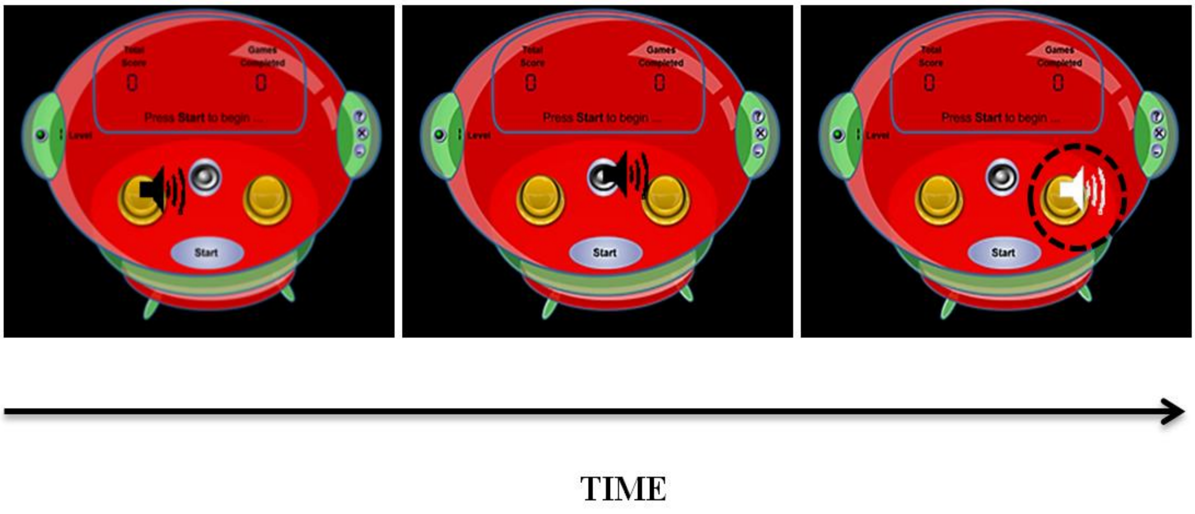



**Figure 5.2: Screen shots of the FD intervention task (McArthur et al., 2008). Three pure tones were presented consecutively. The black speakers depict the standard tone which was played in the first two instances with the pulsing of the first yellow button and the grey speaker. The 'different tone' (i.e., the target tone), depicted by the white speaker, was played with the pulsing of the second yellow button. The child's task was to identify the 'different tone' by selecting the second yellow button.**

Like the test version of the task, the intervention version used a three-interval two-alternative choice (AXB) paradigm. Three consecutive tones, two standard tones, and one 'different tone' (i.e., the target tone) were presented in each trial. The tones were visually depicted as three icons on a 'spaceship' control panel; two yellow buttons and a grey speaker in the middle (see Figure 5.2). The child's task was to identify the target tone by clicking the 'button' that corresponded to the 'different' sound. The frequency of the target tone was adjusted using the PEST algorithm based on the accuracy of the participant's response (see Section 3.9.4 for details of the algorithm). The task ended when the child had made 10 reversals in response adjustment or had completed 60 trials (i.e., the maximum number of trials). Then the child would do the task again until they had completed the task five times which would be the end of their intervention session. Parents were asked to record the date, time, and duration of each intervention session. Therefore, the participant was expected to complete the game a maximum of 120 times.

### 5.7.2 Visual discrimination intervention (VD intervention)

The VD intervention program was included to investigate general exposure to the intervention as a factor. Gillam et al. (2008) found that children who were engaged in an academic enrichment computer program (that focused on mathematics, science, and geography) that was unrelated to the teaching of language ability, nevertheless showed significant improvement in language ability at the end of the intervention phase (see Footnote on pp. 25 for more details). Therefore, they suggested that intervention exposure resulted in improved attention which, in turn, resulted in improved language ability. Hence, the VD intervention was designed to be a 'dummy' intervention, which was included to investigate the effect of intervention exposure per se.

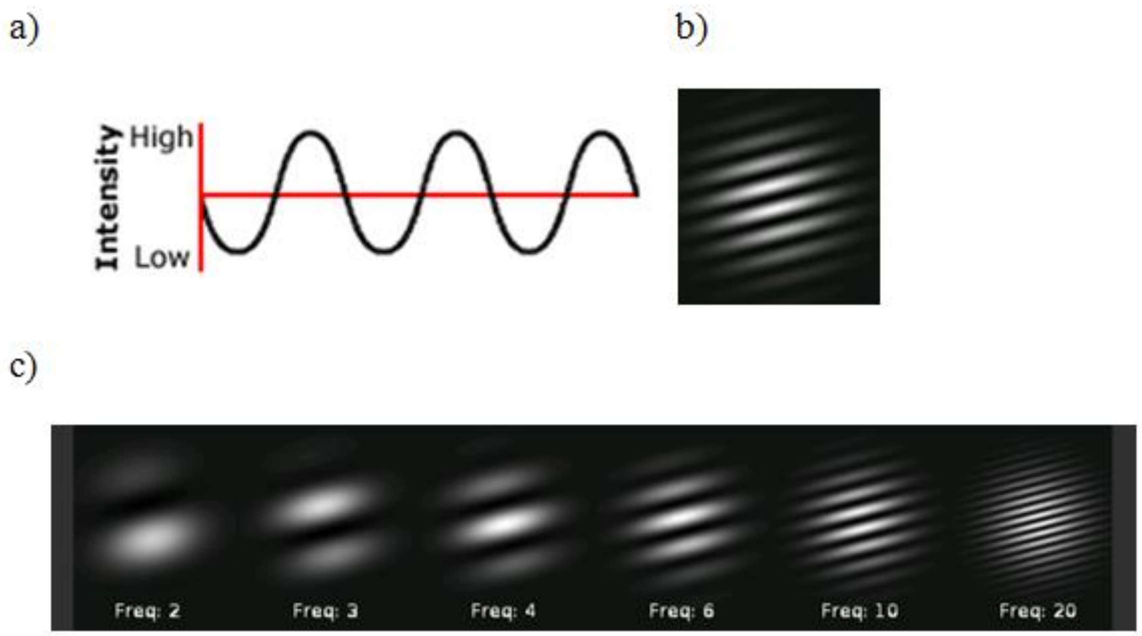



**Figure 5.3: Gabor patches of gratings: a) An illustration of a sine wave function; b) Shows the sine wave function being superimposed on the Gabor patch; and c) Gabor patches of different frequencies. The higher the frequency, the closer the gridlines; the lower the frequency, the further apart they are**

The VD intervention task was designed as a visual analogue of the FD intervention task. The child was presented with the same 'spaceship control panel' with the three icons (i.e., the two yellow buttons separated by the grey speaker). However, instead of using pure tones as stimuli like the FD intervention task, Gabor patches were used (see Figure 5.3). Gabor patches are common stimuli used in visual perception research. They are sine wave gratings in which light intensity alternates between its brightest and darkest values according to a sine function (Figure 5.3a and 5.3b) (Wolfe et al., 2012). Sine wave functions of higher frequencies result in Gabor patches that have ‘lines’ closer together (Figure 5.3c). During the VD intervention task, three Gabor patches were presented consecutively. Two of the Gabor patches have the same sine wave frequency; hence, they looked identical and were the standard stimuli. The remaining Gabor patch was the target stimulus, which had a higher frequency (see Figure 5.4). The child’s task was to identify the target stimulus. Each stimulus was presented for 500ms with a stimulus onset asynchrony of 1000ms. The task used the same adaptive procedure and algorithm as the FD intervention task.

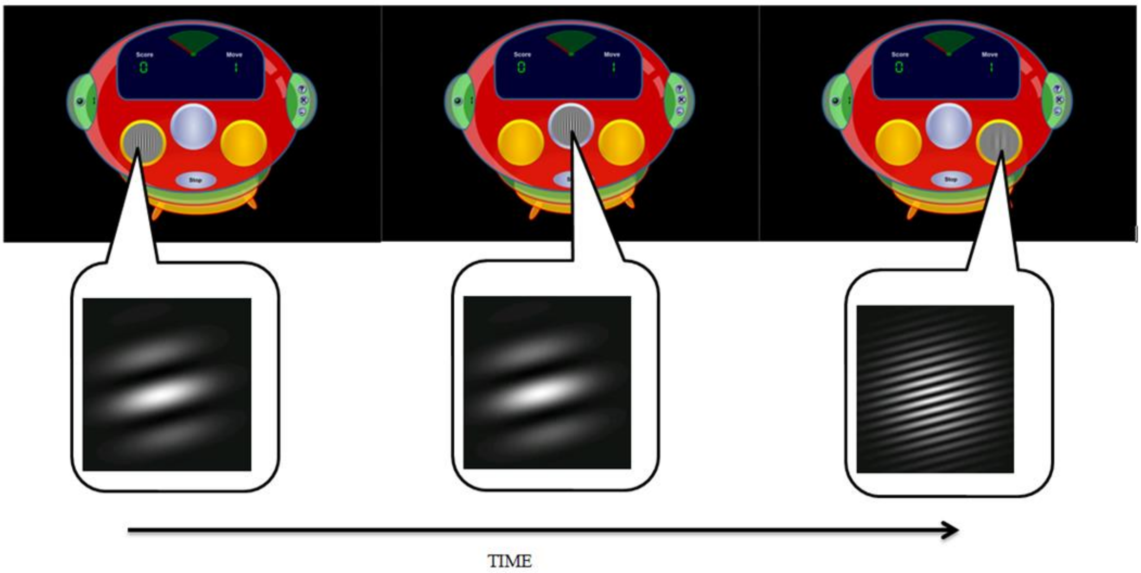



**Figure 5.4: A screen shot of the VD intervention task adapted from McArthur et al. (2008). Gabor patches were used as stimuli. Three Gabor patches were presented consecutively. Two have the same frequencies (the standard stimuli) and the remaining one is a Gabor patch of a higher frequency (target stimulus). The child’s task was to identify the target stimulus.**

Like the FD intervention, the VD intervention had five stages. The participants who undertook the VD intervention were given the same instructions as those undergoing the FD intervention, with one exception: it was explained to the parents that the VD intervention might improve attention and hence, might be beneficial to APD and reading. The participants were to play the game five times and aimed to achieve the highest stage possible. The participants would move through the stages depending on the accuracy of their discrimination. The parents were provided with a log to record the time and duration of the intervention and the final score achieved. Each participant was expected to complete the game a maximum of 120 times. Like the FD intervention, the VD intervention was hosted virtually in a shared folder between the researcher and the participants. The participants accessed the program via their home computer. The researcher monitored the intervention as the intervention data was updated and the files synchronised.

### 5.7.3 Phonological processing intervention (PP intervention)

The PP intervention used was the Reading Sounds 1Pro (Rajkowski, 2003), which is a commercially available program that is used in clinics and many schools in Australia for children with reading difficulties. This computer-based program aims to facilitate literacy development through the strengthening of the letter-sound relationship, blending and segmentation of words through multisensory scaffolding. Activities related to sight words are also part of the program and were incorporated into the present study to facilitate word reading fluency. A large body of research concerning the outcome of similar reading interventions demonstrated that the teaching of letter-sound correspondences and the use of multisensory teaching strategies are effectiveness in improving literacy ability in children (Bus & van IJzendoorn, 1999; Ecalle et al., 2009; Ehri et al., 2001; Joshi & Dahlgren M, 2002; Lynch et al., 2000; Magnan & Ecalle, 2006; Nicholson et al., 2000; Oakland, Black, Stanford, Nussbaum, & Balise, 1998; Simpson, Swanson, & Kunkel, 1992; Tijms, 2011).

The PP intervention comprised a series of listening activities in the form of arcade-style games. The activity interface comprised the ‘control panel’ and the ‘tile display area’ (see Figure 5.5). The control panel included a ‘visual support screen’ for the display of visual cues, and an ‘articulatory cue screen’ which displayed the articulatory gestures associated with the targeted phonemes. The targets to be mastered were presented on ‘tiles’ in the ‘tile display area’. In each activity, the child was presented with a verbal stimulus, e.g., “Can you find /r/ like in ‘road’?” and was required to use the computer mouse to click on the corresponding tile (i.e., the tile that corresponded to ‘r’).

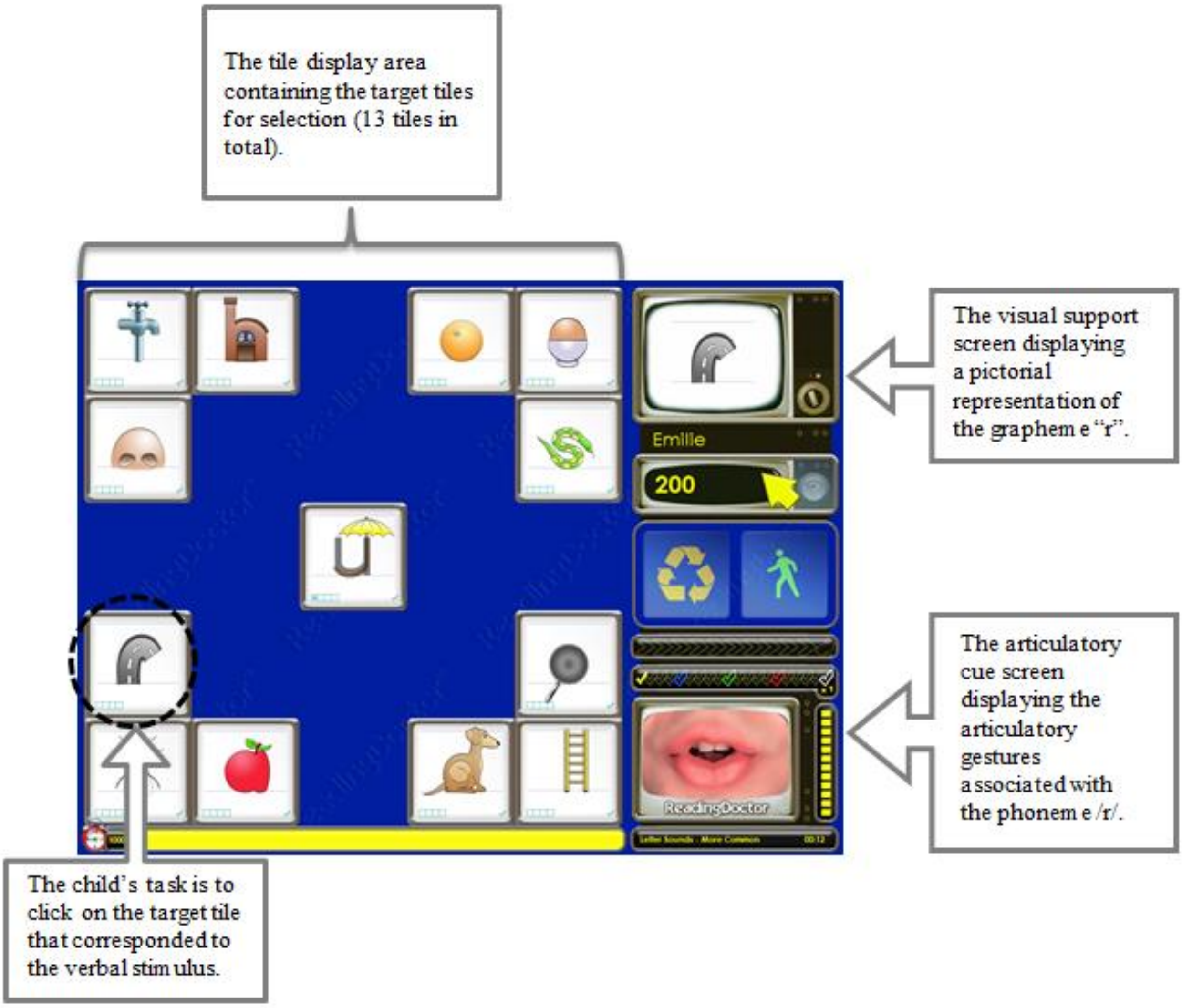


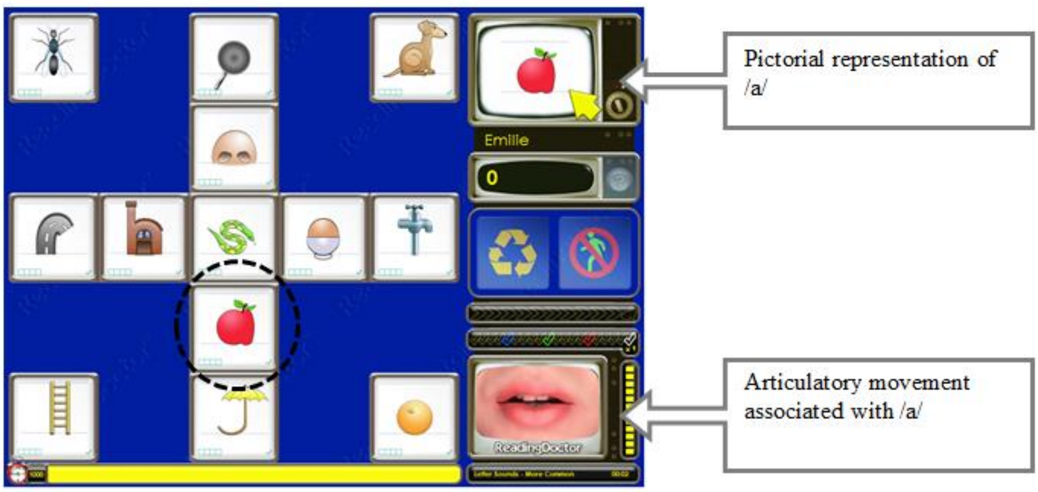

**Figure 5.5: A screen shot of the PP intervention program adapted from Rajkowski (2003) that shows the presentation of the stimulus /r/ in a Letter Sounds activity. The verbal stimulus was “Can you find /r/ like in ‘road’?” The visual support screen displays the pictorial representation of ‘road’ and the articulatory cue screen displays the associated articulatory gesture of the /r/ phoneme. The child’s task was to click on the target tile that corresponded to the verbal stimulus.**

The intervention program is scaffolded so that the initial presentation of each stimulus is accompanied by both visual and auditory cues. These are referred to as ‘mnemonics’, as they act as devices to aid information retention and facilitate learning. The mnemonics include a pictorial representation of the sound or word that is meaningful to children, the articulatory gestures that correspond to the sound or word, and a verbal description of the word. When the child responds correctly to the stimulus, the mnemonics will fade out and, eventually, the child will discriminate between the stimuli independently (see the series of screenshots in Figure 5.6). The mnemonic support returns if the child responds incorrectly. There are 62 activities which are categorised under the following six categories: 1) Letter Sounds; 2) Blending; 3) Segmentation; 4) E Rule; 5) Word Grids; and 6) Sight Words.

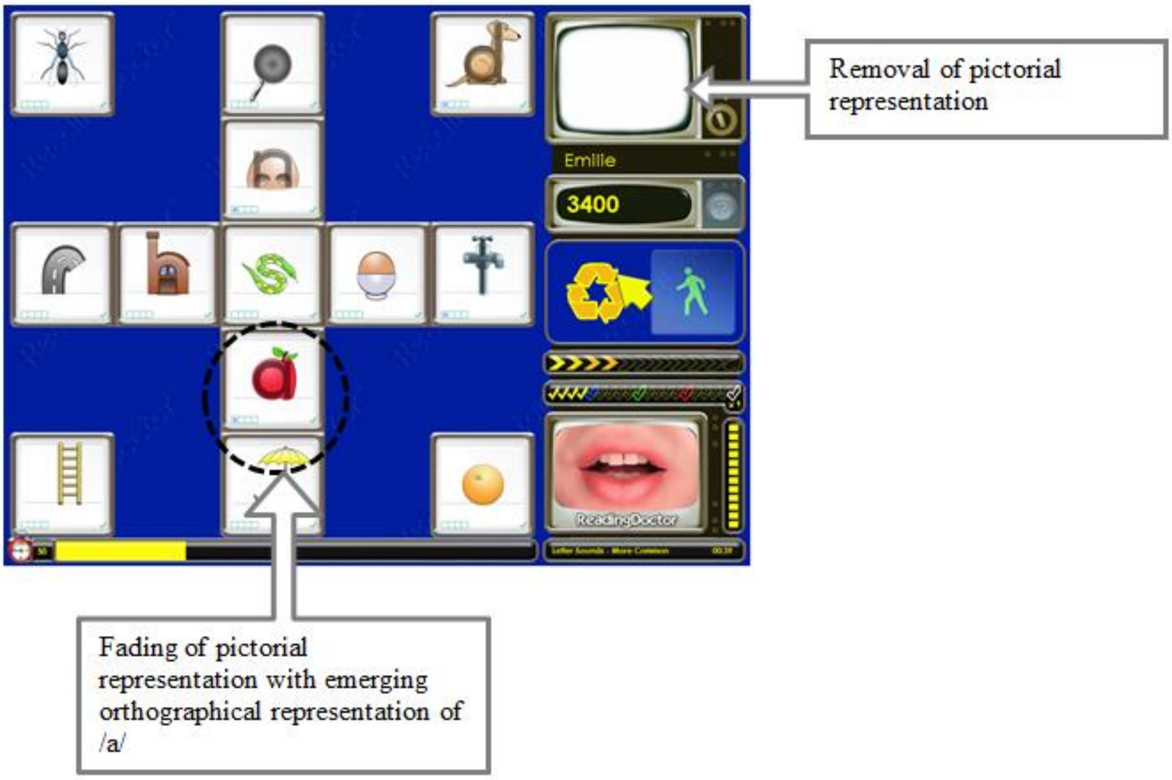
#### *5.7.3.1 Letter Sounds*

The Letter Sounds activities aim to teach children to relate phonemes to their corresponding grapheme. The stimuli included 25 single letter sounds which consisted of 20 consonants (b, c, d, f, g, h, j, k, l, m, n, p, r, s, t, v, w, x, y and z) and five short vowels (a, e, i, o and u). Each activity begins with the standard instruction: “Let’s play a listening game. Find the letter sounds as quickly as you can.” This was followed by the presentation of the verbal stimulus, for instance: “Can you find /a/ like in ‘apple’?” The child’s job is to click on the ‘tile’ that corresponds to the phoneme /a/ (see the series of screenshots in Figure 5.6, below).

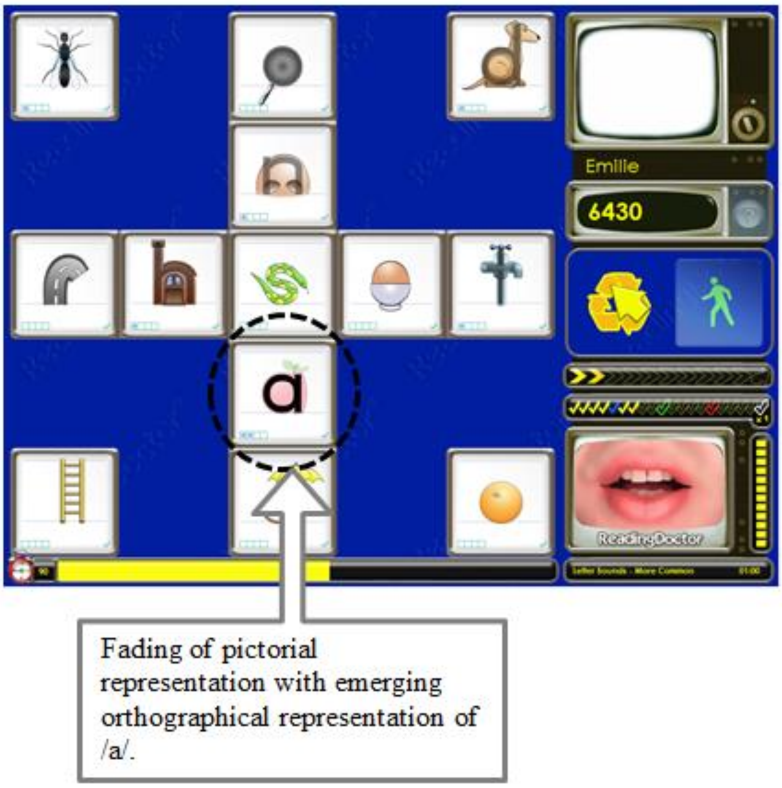
a) Initial presentation of the stimulus /a/. Verbal stimulus: “Can you find /a/ like in ‘apple’?”



b) Second presentation of the stimulus /a/. Verbal stimulus: “Find /a/ like in ‘apple’?”




c) Third presentation of the stimulus /a/. Verbal stimulus: “/a/ like in…?”



d) The fourth presentation of the stimulus /a/. Verbal stimulus: “/a/”

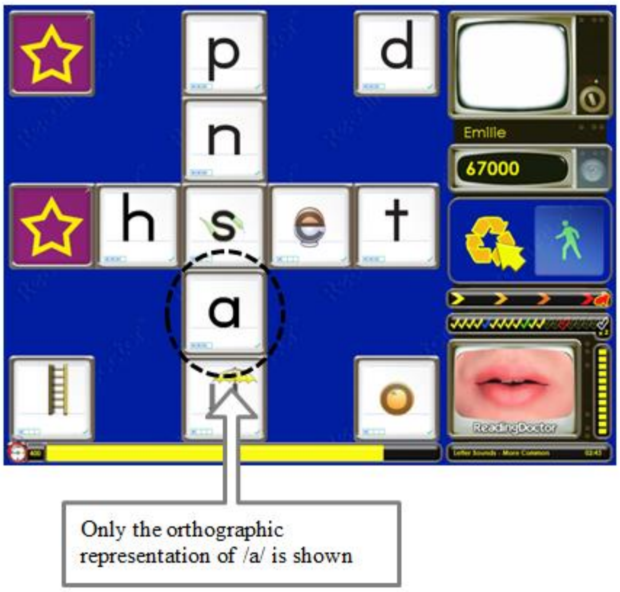



**Figure 5.6: An example of a Letter Sound Activity associated with the presentation of the stimulus /a/. This series of screen shots adapted from Rajkowski (2003) shows the fading out of mnemonics on the subsequent presentation of the stimulus as the child responded correctly.**

There are seven Letter Sounds activities. They vary in terms of the letter sounds targeted, whether the mnemonic support is available or only present when the child made an incorrect response, and the number of tiles presented. The participants undertook activities in a sequential order (from Activity 1 to Activity 7). They could move on to the next activity if there were two or fewer errors in their response selection. If there were more than two errors, the child would have to repeat the same activity again.

### *5.7.3.2 Blending*

The Blending activities aim to teach children to use letter-sound knowledge to construct single words of different word structures, i.e., the CVC, CCVC, and CVCC structures, where ‘C’ denotes a consonant and ‘V’ denotes a vowel. Figure 5.7 shows an example of one of the blending activities, the blending of CVC words.

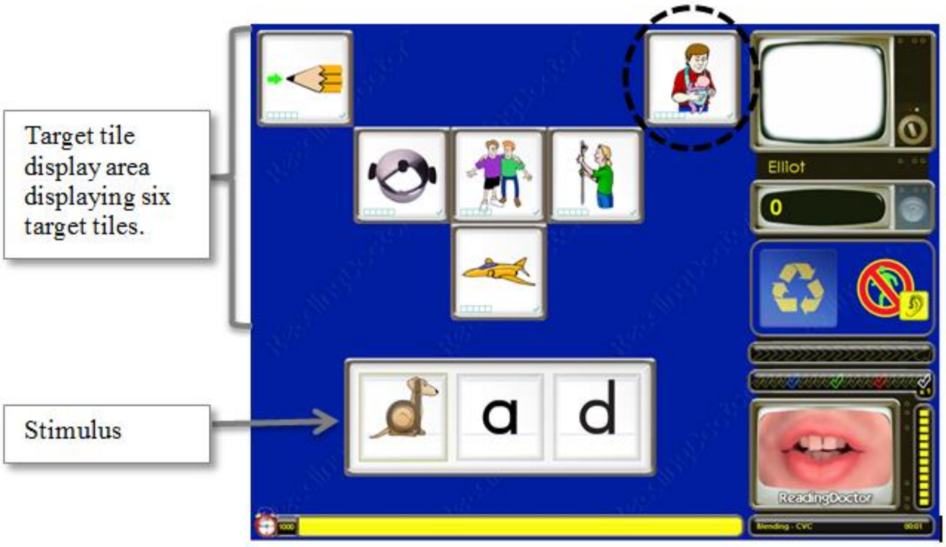



**Figure 5.7: A screen shot of the CVC Blending Activity that contains six target tiles adapted from Rajkowski (2003). The stimulus presented was the written word 'dad'. This was accompanied by the verbal stimulus "/d/…/a/…/d/… dad. Dad is carrying the baby." The child's task was to join the sounds together to make the word and to click on the picture that corresponds to the word, 'dad'.**

Each activity begins with the standard instruction, "Let's play a listening game. This game will teach you how to join letter sounds together to read words. Move the mouse over the tiles at the bottom of the screen to help you join the sounds and read the word. Then click on the right tiles as fast as you can …" The top half of the tile display area presents the target tiles, which are the pictorial representations of the CVC words. The bottom of the screen presents the written word (e.g., in the example shown in Figure 5.7, it was 'dad'). This is accompanied by the verbal stimulus, "/d/…/a/…/d/… dad… Dad is carrying the baby." The child's task is to blend the phonemes together to make the word and to click on the picture that corresponds to that word, e.g., 'dad'.

There were 18 Blending activities. They varied in terms of the word structure of the stimuli words (e.g., CVC, CCVC, CVCC etc.) and whether they were 'easy' words or words that were more difficult, the number of target tiles (six or 15 tiles), and whether the mnemonic support was available or that it would only be present when the child made an incorrect response. Like the letter sounds activities, the participants worked through the blending activities in a sequential order (from Activity 1 to Activity 18). They could move on to the next activity if there were two or less errors in their response selection. If more than two errors were made, the child would have to repeat the same activity again.

#### *5.7.3.3 Segmentation*

The Segmentation activities aim to help children to use their letter-sound knowledge to break a word up into its constituent letter-sounds. Like the blending activities, single words with the CVC, CCVC, and CVCC structures are targeted. Each activity begins with the standard instruction, “Let’s play a word making game. This game will teach you how to use letter sounds to make words …”

Figure 5.8 shows an example of one of the segmentation activities, the segmentation of CVC words. The tile display area shows the pictures of the six words involved in the activity (on the sides) and the letters for response selection (in the middle, see Figure 5.8). The visual support screen shows the picture of the word, for instance, the word was ‘mum’ in the example shown in Figure 5.8. The articulatory cue screen shows the articulatory gestures associated with the different phonemes, which is /m/, /u/ and /m/ in this example. Each trial begins with the verbal stimulus, “Can you make the word ____ … (a sentence with the word in it)”, e.g., “Can you make the word mum … Mum is carrying the baby.” The child’s task is to click on the graphemes that correspond to the word, in this case, ‘mum’.

There were ten Segmentation activities. They varied in terms of the structure of the words involved and whether the words were ‘easy’ or difficult words, and whether the mnemonic support was available or that it would only be present when the child made an incorrect response. Like the activities in the previous categories, the participants worked through the Segmentation activities in sequential order (from Activity 1 to Activity 10). They could move to the next activity if there were two or fewer errors in their response selection. If more than two errors were made, the child would have to repeat the same activity again.

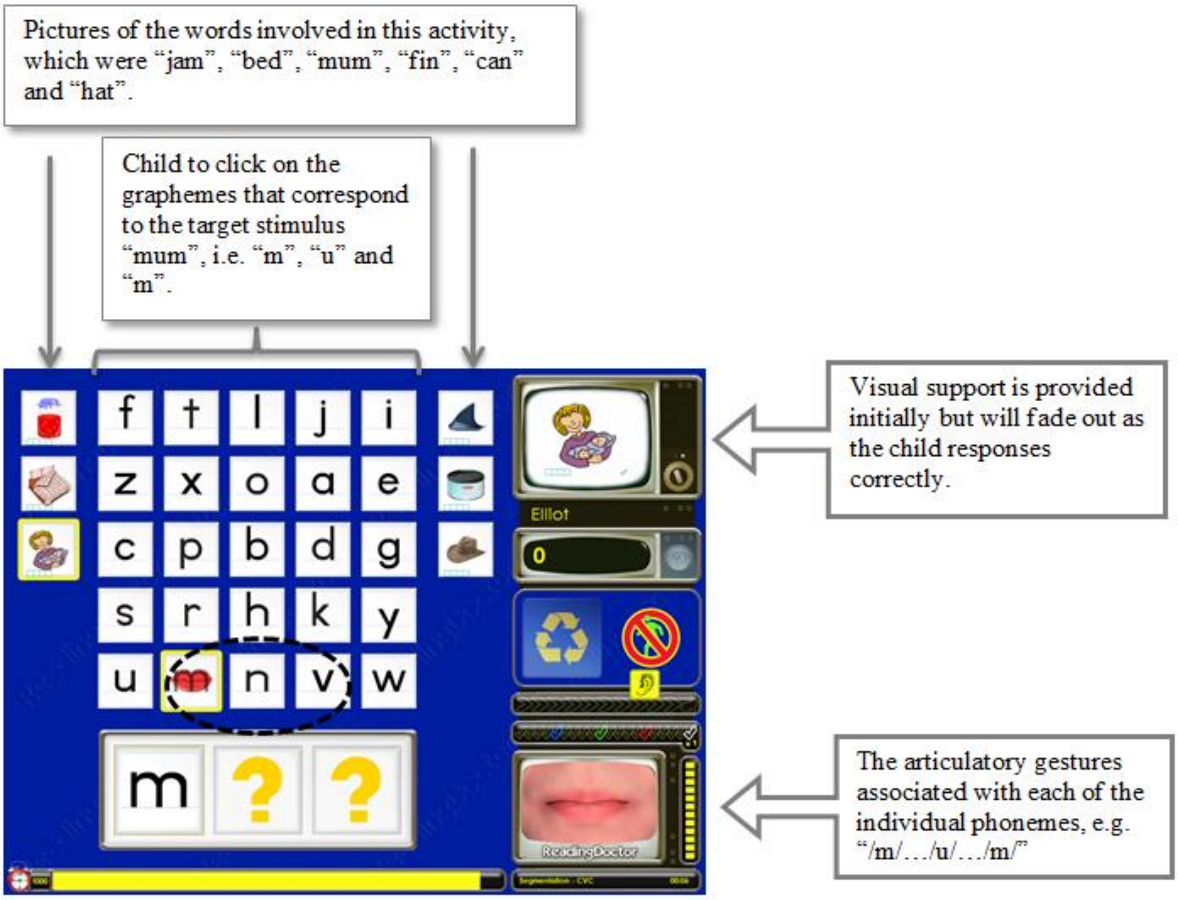



**Figure 5.8: A screen shot of the segmentation activity involving the CVC words: jam, bed, mum, fin, can, and, hat adapted from Rajkowski (2003). The tile display area shows the pictures of the words 'jam', 'bed', 'mum', 'fin', 'can', and 'hat' and the graphemes that are available for response selection. The visual support screen shows the picture of 'mum'. The articulatory cue screen shows the articulatory gestures associated with the phonemes /m/, /u/ and /m/. The trial begins with the verbal stimulus, "Can you make the word mum … Mum is carrying the baby." The child's task is to click on the graphemes that correspond to the word 'mum'.**

### *5.7.3.4 E Rule*

The E Rule activities aim to teach children the following literacy pattern; when adding an 'e' to the end of a word, this may change the reading/pronunciation of the preceding short vowel into a long vowel. Each activity begins with the standard instruction of "Let's play a listening game. This game will teach you what the letter 'e' does at the end of words. I will say a word and you use the mouse to click on the right tiles as fast as you can."

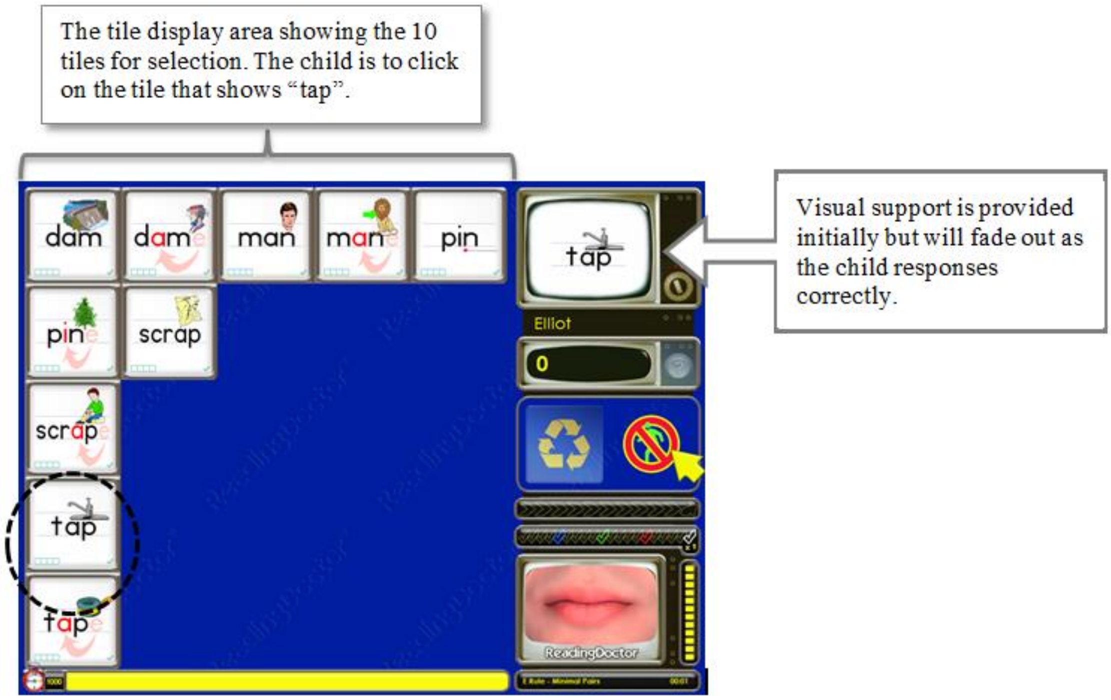



**Figure 5.9: A screen shot of an E Rule activity with minimally-paired words adapted from Rajkowski (2003). The verbal stimulus was, "Can you find tap? Water is leaking out of the tap." The child's task was to click on the tile showing 'tap'.**

Figure 5.9 shows an example screen shot of one of the E Rule activities involving minimally-paired words (e.g., 'tap' and 'tape', 'dam' and 'dame', and 'man' and 'mane'). The tile display area shows the target tiles of the minimally-paired words involved in the activity. Each trial begins with the verbal stimulus, "Can you find (word) … (a sentence with the word in it)." For instance, in the example shown in Figure 5.9, the verbal stimulus was, "Can you find tap? Water is leaking from the tap." The child's task is to click on the tile showing the word 'tap'.

There were eight E Rule activities. They varied in terms of the types of words used (i.e., whether they were minimally-paired words (e.g., 'hop' vs. 'hope', 'man' vs. 'mane', and 'pin' vs. 'pine') or minimally-paired word endings (e.g., 'op' vs. 'ope', 'ib' vs. 'ibe', and 'an' vs. 'ane'), the numbers of tiles used in the activity (10 or 24), and whether the mnemonic support was available or that it would only be present when the child made an incorrect response. Like the activities in the previous categories, the participants worked through the E Rule activities in sequential order (from

Activity 1 to Activity 8). They could move to the next activity if there were two or less errors in their response selection. If more than two errors were made, the child would have to repeat the same activity again.

#### *5.7.3.5 Word Grids*

The Word Grid activities aim to improve children's word reading fluency. It requires them to discriminate between words that are visually similar. Each activity begins with the standard instruction, "Let's play a listening game. This game will teach you how to read words quickly. I will say a word and you use the mouse to click on the right tile as fast as you can …" Figure 5.10 shows an example of one of the word grids activities involving CVC words (e.g., 'cup', 'fed', 'jug', and 'fix'). The tile display area shows the target tiles that are involved in the activity. Each trial begins with the verbal stimulus, "Can you find?" For instance, in the example shown in Figure 5.10, the verbal stimulus was, "Can you find jug?" The child's task is to click on the tile that shows 'jug'.

There were ten Word Grid activities. Each activity was concerned with words that were visually similar in some respect, e.g., in terms of their word structure (CVC, CCVC, or CVCC), words that begin with the same letter (e.g., words that begin with s-clusters such as spin, span, smile, snail), words that end with similar endings (e.g., words that have n-clusters at the end of words, e.g., blind, blunt, and, ant). Like the activities in the previous categories, the children worked through the Word Grid activities in sequential order (from Activity 1 to Activity 10). They could move on to the next activity if there were two or less errors in their response selection. If more than two errors were made, the child would have to repeat the same activity again.

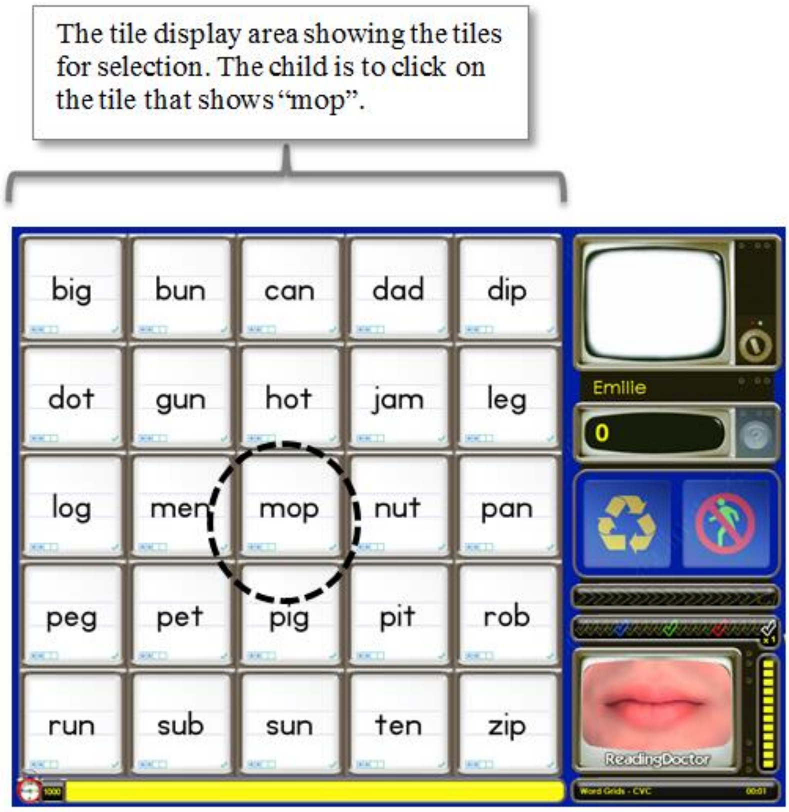



**Figure 5.10: A screen shot of the word grid activities involving CVC words adapted from Rajkowski (2003). The verbal stimulus was, "Can you find <u>mop</u>?" The child's task was to click on the tile that shows 'mop'.**

### *5.7.3.6 Sight Words*

The Sight Word activities aim to help children recognise the most common words in written English and words that are irregularly spelt. Each activity begins with the standard instruction of, "Let's play a listening game. This game will teach you the most important words for reading. I will say a word and you use the mouse to click on the right tile as fast as you can ..." Figure 5.11 shows an example of one of the sight words activities involving two-letter sight words (e.g., 'of', 'is', 'an', and 'do'). The tile display area shows the words involved in the activity. The child's task is to click on the tile that corresponds to the verbal stimulus presented.

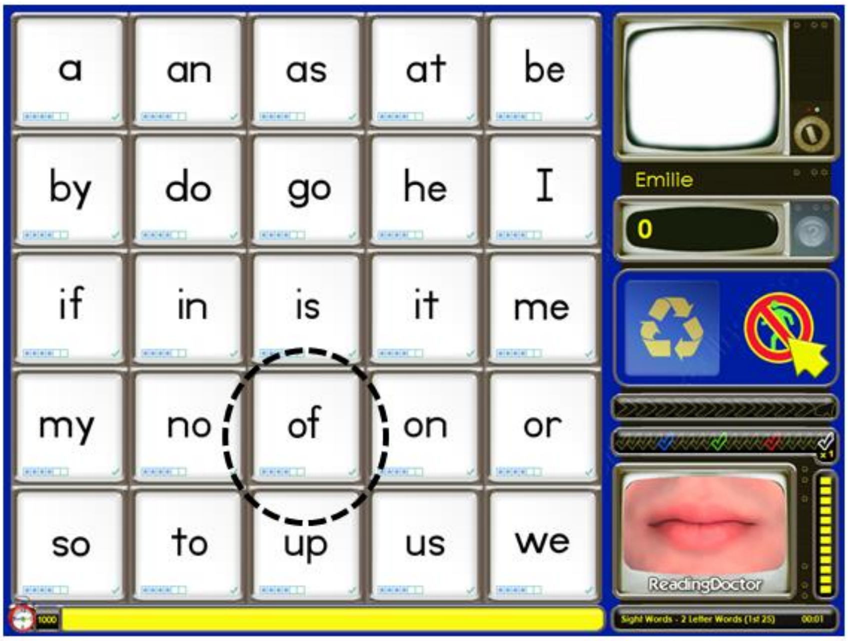



**Figure 5.11: A screen shot of the Sight Words activity that involved two letter sight words adapted from Rajkowski (2003). The verbal stimulus was, "Of … lots of bees". The child's task was to click on the tile that showed the word 'of'**

There were nine Sight Words activities. They varied in terms of the number of letters the words had (e.g., 2-letter words, 3-letter words, and 4-letter words) and their word frequency (e.g., the first 25 most commonly-used words, the second 25 most commonly-used words). There were also activities involving homophones (e.g., 'here' and 'hear', 'be' and 'bee') and words that looked similar, but had different syntactic functions (e.g., 'of' vs. 'off', 'an' vs. 'and'). Like the activities in the previous categories, the children worked through the Sight Words activities in sequential order (from Activity 1 to Activity 9). They could move on to the next activity if there were two or less errors in their response selection. If more than two errors were made, the child would have to repeat the same activity again.

Children undertook the PP intervention at home using their home computer. The researcher introduced and demonstrated the PP intervention and its setup to the parents prior to the commencement of the PP intervention. Parents were asked to record the date and duration of the intervention for each activity.

## 5.8 Outcome Measures/Assessments

Four different (potential) intervention effects were used to assess the effect(s) of both FD and PP interventions, as well as their combined effects. They were: 1) the intervention-specific effect, i.e., the changes in performance on the actual intervention tasks post-intervention; 2) the maintenance effect of the intervention-specific effect(s); 3) the generalisation of potential intervention effects or improvement to another task similar to the intervention task (i.e. the within-task generalisation); and 4) the generalisation of potential intervention effects or improvement to another cognitive ability, including word reading, receptive vocabulary, and receptive grammar/sentence comprehension.

**Table 5.1: The measures used for the intervention-specific effect, the within-task generalisation effect and the generalisation effect to reading and language of the FD and PP intervention**

| Intervention | Effects | Measures |
|---|---|---|
| **FD** | Intervention-specific | SoundsPod |
| | Within-task generalisation | Dinosaur Task |
| | Generalisation to phonological awareness, reading, and language | ALNLRAC, PPVT-4, and TROG |
| **PP** | Intervention-specific | PP Intervention Test |
| | Within-task generalisation | CTOPP |
| | Generalisation to reading and language | ALNLRAC, PPVT-4, and TROG |

KEY: PP Intervention Test = the Phonological Processing Intervention Test; PPVT = the Peabody Picture Vocabulary Test 4th Edition; TROG = the Test of the Reception of Grammar; CTOPP = the Comprehensive Test of Phonological Processing; ALNLRAC = the Assessment of Lexical and Non-Lexical Reading Ability in Children

Table 5.1 shows the assessment measures used for the intervention-specific effect, the within-task generalisation effect, and the generalisation effect to reading and language of the FD and PP intervention programs. The SoundsPod, CTOPP, PPVT-4, TROG, and ALNLRAC were also used in Study 1, and a detailed description of these tests can be found in Sections 3.9.4, 3.10.3, 3.10.4, 3.10.1, and 3.10.2 respectively. Details of the Dinosaur Task, which was used to evaluate the within-task generalisation of FD intervention, and the Phonological Processing Intervention Test, which was used to evaluate the intervention-specific effect of the PP intervention, are provided below.

### 5.8.1 Within-task generalisation of the FD intervention: The Dinosaur Task

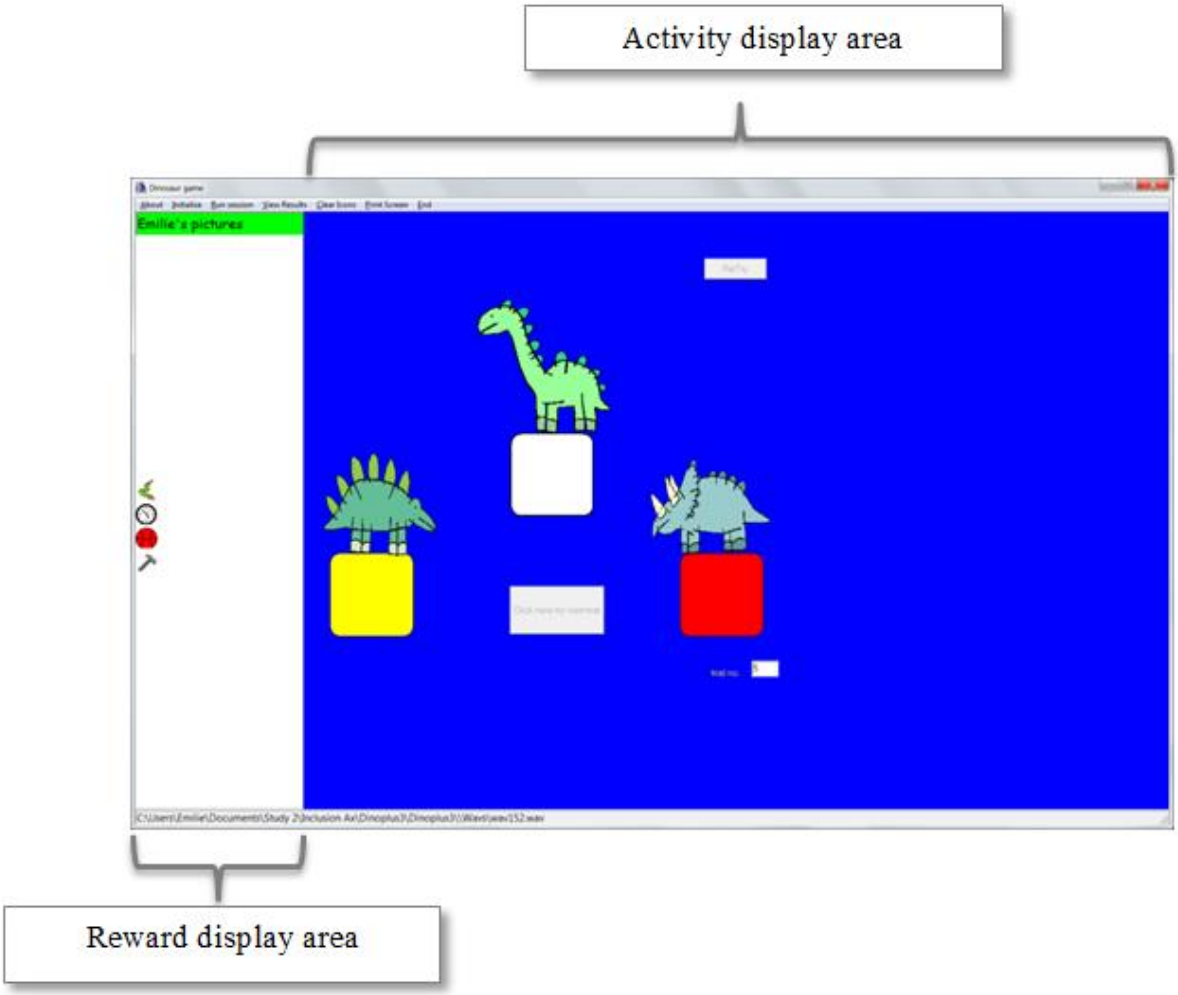



**Figure 5.12: The activity interface of the Dinosaur Test (Halliday & Bishop, 2006). The activity display area shows three dinosaurs which represent the three tones (two standard tones and a target tone) that are presented consecutively. The child's task is to click on the dinosaur that represents the target tone. The reward display area shows the cartoon pictures that appear if the child responds correctly**

The Dinosaur Task is a psychoacoustic task that was used by Halliday and Bishop (2006). It has also been used in other studies concerning AP abilities in children (Hill et al., 2005; Mengler et al., 2005). This is a not a standardised test and therefore its psychometric properties are unknown. It was selected for use in the present study as a measure of the potential within-task generalisation effect for the FD intervention, mainly because of the similarities between the two tasks/tests of FD, i.e., the SoundsPod and the Dinosaur Task. Both tasks employ a three-interval, two alternative forced choice (AXB) paradigm, where ‘A’ and ‘B’ refer to the two intervals at which the target tone could occur, and ‘X’ is the interval that always contains the standard tone. The child’s task is to use the computer mouse to click on the pictorial representation of the tone that is different. Additionally, the two FD tasks have stimuli of similar characteristics. Both tasks employ tones that are 100ms in duration and an inter-stimuli-interval of 500ms. However, the two FD tasks differ in their activity interface and employ a different algorithm for response adjustment.

##### *5.8.1.1 Test procedure of the Dinosaur Task*

Figure 5.12 shows the activity interface of the Dinosaur Task. The interface is divided into two sections: 1) an activity area; and 2) a reward display area. The activity display area shows cartoons of three dinosaurs. The first tone is visually represented on the screen by a cartoon picture of a dinosaur that jumps up when the tone is played. The second tone is represented by the second dinosaur, which is the standard tone (600Hz) and remains as the standard tone throughout the game. The third tone is represented by the third dinosaur. The target tone or the ‘different tone’ has a higher frequency that is variable between 600Hz to 1000Hz, and is randomly assigned to either the first or the third tone. The remaining tone has the same frequency as the standard tone (600Hz). The child’s task is to use the computer mouse to click on the dinosaur that makes a different sound.

A standard set of instructions were given to the participants before the beginning of the task, “You will see three dinosaurs on the computer screen. Two of the dinosaurs are going to make the same sound and one is going to make a different sound. Your job is to click on the dinosaur that makes a different sound. Either the first or the third dinosaur will be the ones making the different sound. We will do a few practices.”

The examiner proceeded by presenting the first trial and demonstrating the correct response. This was followed by three practice trials. When the participant correctly identified the target tone in all three trials, the testing commenced. If not, feedback was given and the practice trials were repeated until the child responded correctly two out of three times.

A novel cartoon icon appears and remains visible on the reward display area when the child responds correctly. This is accompanied by an upward sweeping sound. When the response is incorrect, a black cross appears and is accompanied by a ‘sigh’ sound. The child is given unlimited time to respond. Before each new trial begins, the child is required to click a ‘box’ to start the new trial. This is to make sure that the participant is ready to attend to the stimuli at the beginning of each trial.

Like the SoundsPod, the frequency of the target tone corresponded to the different ‘levels’ on a stimulus continuum, ranging from Level 0 to 200. The standard tone has a frequency of 600Hz, and it is referenced as Level 0. The frequency of the target tone can vary from level 0 (i.e., being the same frequency as the standard tone, at 600Hz), to level 200 (i.e., 400Hz higher in frequency than the standard tones, at 1000Hz). 1-unit of change in frequency or ‘step-size’ (e.g., from level 2 to level 1) equates to a frequency reduction of 2Hz, which is the smallest unit of change or ‘the smallest step-size’. The largest step-size is 50, which equates to 100Hz. The task begins with the largest step-size until an error is made and then a reversal in response adjustment occurs and the frequency difference between the standard tones and the target tones increases.

The initial target tone has a frequency of 1000Hz. If the child responds correctly, the frequency of the target tone is reduced so that the frequency difference between the target tone and the standard tone becomes smaller until an error is made. Once an error is made, a reversal occurs and the difference between the standard and target tone increases. The PEST algorithm governs the changes in step sizes based on the child’s responses, so that the child is responding correctly 75% of the time. The task ends when the participant has made eight reversals in response adjustment or has completed 80 trials (i.e., the maximum number of trials possible in a game). The task takes 10 to 15 minutes to complete.

#### *5.8.1.2 Scoring of the Dinosaur Task*

Like the SoundsPod, a FD threshold score, i.e., the FD-DINO-TS (measured in Hz) is generated at the end of the Dinosaur Task. This is an indication of the child's FD ability. It is also calculated to be the mean frequency difference between the target and standard tones from the 6$^{th}$ to 10$^{th}$ reversal in response adjustment. On the one hand, a larger threshold score value meant that the child required a larger frequency difference to discriminate between the target and the standard tone, i.e., poorer FD ability. On the other hand, a smaller value indicates that the child required a smaller frequency difference to discrimination between the tones, i.e., better FD ability.

### 5.8.2 PP Intervention Test

The PP Intervention Test is used to evaluate the intervention-specific effect of the PP intervention. It assesses the participant's ability to read and write the target stimuli that were used in the PP intervention. This is a not a standardised test and therefore its psychometric properties are unknown. The PP Intervention Test consists of 80 items for reading and the same 80 items are included in the writing task. The items are the letter sounds and words that are targeted in the PP intervention.

#### *5.8.2.1 Test procedure of the PP Intervention Test*

For the reading task, ten test items were presented on a single page (e.g., 10 CVC words – 'man', 'put' etc.). A standard set of instructions was then given: "I am going to show you a page with different letters or words on it. I want you to read them out the best you can." The child's task was to read the words out loud.

The writing task involves the examiner presenting the same test items verbally, while the child's task was to repeat the test item and then write it down. A standard set of instructions was also given, "I am going to say a word and I am going to put the word in a sentence. I want you to repeat the word and then write it down."

For example:

Examiner: "log … A log of wood is lying on the ground …. log"

Participant: "log" and attempt to write 'log'

The PP Intervention Test took 20 to 30 minutes to complete.

#### *5.8.2.2 Scoring of the PP Intervention Test*

The raw score (i.e., the PP Intervention Literacy Score, the PP-I-LS), which was the total number of correct responses out of 80 items, was used in the statistical analysis.

## 5.9 Places Where the Research was Undertaken and Equipment

The intervention took place in the participant's home, supervised by parents. Parents were instructed that it should be carried out in a quiet room, free from distraction. The assessments were conducted by the researcher and took place in a quiet room, either at the participant's home, or at the Speech and Audiology Clinic at Flinders University.

Each participant in the three intervention groups was given an external soundcard (Creative SoundBlaster X-Fi Go!) and a pair of headphones (Sennheiser HD 202). These were used during the assessment sessions and the intervention sessions to ensure that the audio output from the different computers remained consistent.

## 5.10 Strategies to encourage compliance in the intervention

A number of strategies were employed to encourage compliance to the intervention schedule for those in the intervention group. Firstly, parents were given written instructions describing the procedure, frequency, and duration of intervention. Secondly, the researcher monitored the training exposure through the shared folder which contained the data concerning the time and duration of access of the intervention programs; and thirdly, performance during each intervention phase was automatically updated by the intervention programs. This provided objective information related to intervention compliance. Section 6.2 shows the results for the comparisons of the amount of intervention received by the three intervention groups. Additionally, parents were asked to keep a record of the date and time of each intervention. Finally, the children were told that their participation and diligence would contribute towards a gift voucher at the end of their participation in the study. The children in the CON group were given access to the PP intervention program and the same honorarium gift card after the final assessment.

## 5.11 Statistical Analysis

### 5.11.1 Sample size estimation

A priori power analysis was conducted using a power analysis software known as the G*Power Version 3.1.0 (Faul, Bunchner, Erdfelder, & Lang, 2001). The calculation was based on a statistical analysis using an ANOVA with four experimental conditions and repeated measures of four observations with both within- and between-factor analyses, assuming that the data would meet the required parametric assumptions. In order to detect a medium ($f = 0.25$) or large effect size ($f = 0.40$), with a power of 80%, and a hypothesised type I error of $\alpha = 0.05$, a total sample size of 36 or 16 participants were needed respectively. This assumed that the correlation between the repeated measures was $r = 0.5$.

Much effort was put into recruitment. However, due to time constraints and the unforeseen circumstance of one of the clinics being unable to continue their participation in the study, only a modest number of 19 participants were recruited.

Subsequently, a sensitivity power analysis was conducted to investigate the magnitude of the effect size that the present study was able to detect. The results showed that, based on a power of 80% and a type I error of $\alpha = 0.05$, the maximum level of effect size that could be determined was a medium-large effect size of at least $f = 0.35$.

### 5.11.2 Missing data handling

The attrition of two participants during the course of the study led to a small portion of missing data (3.7% of the whole data set). An analysis was conducted to explore the nature of the missing data mechanism. Little's MCAR (Missing Completely At Random) Test (Little, 1988) was used to investigate whether the 'missingness'[15] in the present data set satisfied the assumptions of MCAR, that is the probability that the missing value is independent of both the observed data set and the missing values. The results showed that the missingness was indeed MCAR (Chi-Square = 0.00, df = 1002, p = 1.00). Therefore, there should be no systematic differences between the variables that have missing data and those that do not, that is, the data were 'observed at random' (McKnight, McKnight, Sidani, & Figueredo, 2007).

A literature review was conducted to investigate the different missing data handling methods. Model-based imputation techniques, such as multiple imputation, maximum likelihood estimation for missing data, and Expectation Maximization are commonly recommended over ad hoc methods, such as available case analysis, complete case deletion, mean substitution, and last observation carries forward. This is because of their ability to preserve power and to provide a complete data set which is necessary for conducting modelled-based analyses for significance testing (such as the permutational ANOVA with repeated measure that was used in the present study). They are also able to generate unbiased parameter estimates under the weaker assumption of *missing at random*, i.e., when the probability of the missingness is dependent on other observed variables, but are unrelated to the underlying values of the variable itself, a weaker assumption than

[15] 'Missingness' is a term used in statistics that refers to the manner in which data are missing from a sample of a population (Allison, 2002).

MCAR (Allison, 2002; Enders, 2001; Enders & Bandalos, 2001; Muthen, Kaplan, & Hollis, 1987; Schafer & Graham, 2002). Therefore, the decision was made to use the EM algorithm for missing data estimation.

### 5.11.3 Significance testing using the permutational approach

Significance testing was conducted using permutation tests, which are also known as randomisation tests[16]. As this method of analysis is not widely known, the following summary description is provided.

Permutation tests are a group of statistical tests that are used to evaluate the significance of the results by examining the way the data might have looked if the condition or treatment had shown no effect, by recalculating the test statistic after random re-assignment of the data into experimental groups (Anderson, 2001; Cousineau, 2011; Edgington, 1995). The permutation approach to significance testing was chosen over the more routinely used parametric approach because, on examination of the obtained data set, there were violations of the parametric assumptions mainly due to the small sample sizes within the four groups. When sample sizes are small, the distribution of the data is likely to be compromised, and is likely to violate the parametric assumptions. On the other hand, the tolerance to assumption violation of the parametric tests decreases as sample size reduces. This was demonstrated by Edgell and Noon (1984) in an extensive simulation study investigating the robustness of the *t* test. They found that the *t* test did not produce valid results when the sample size was small ($n = 5$) or when the distribution of both variables were extremely non-normal.

The permutation test has been found to generate unbiased inferences in small-n studies. This is because it permits valid statistical inferences in the absence of parametric assumptions (Anderson, 2001; Cotton, 1973; Cousineau, 2011; Edgington, 1966, 1995; Hayes, 1996; Manly, 1997; Pohlmann, Perkinds, & Brutten, 2002; Siegel & Castellan, 1988; Todman & Dugard, 2001).

[16] Significance testing involved several analytical steps that are outlined at the beginning of Chapter 6.

Parametric tests compare the observed test statistic (e.g., the difference between the means of two groups, or the *t* or *F* statistics) with a theoretical, normally-distributed sampling distribution of the test statistic given that the null hypothesis is true. Hence, the validity of the inferences drawn from parametric tests relies on the assumptions of normality of distribution and homogeneity of variance to be met.

However, the permutation test compares the observed test statistic in relation to the 'permutation distribution' of the test statistic based on the permutation, or resampling, of the obtained data set, assuming the null hypothesis is true. In other words, after the computation of the obtained test statistic, the data set is scrambled and the scores are reassigned randomly to the groups according to the design of the study. The test statistic is recomputed in the resampled data set. This process is repeated as many times as possible so that all possible permutations of the data set have been enumerated and a permutation distribution is constructed (Edgell & Noon, 1984; Hayes, 1998; Hesterberg, Monaghan, Moore, Clipson, & Epstein, 2003; Hope, 1968; Manly, 1997; Todman & Dugard, 2001).

The validity and the power of the permutation test and the parametric tests have been compared in a number of studies. For instance, Darlington (1990) found that under non-normality, the permutation test produced accurate tests of regression parameters. Hayes (1996) found that the permutation test was as valid as the *t* test when sampling from a non-normal distribution, and that it had better control of type I error rates compared to the *t* test, when extreme non-normality was paired with small sample size. Mewhort (2005) found that, under most circumstances, the *F*-test and the permutation test produced similar results. However, the permutation test was more powerful than ANOVA while maintaining the same type-I error rate when the error was skewed.

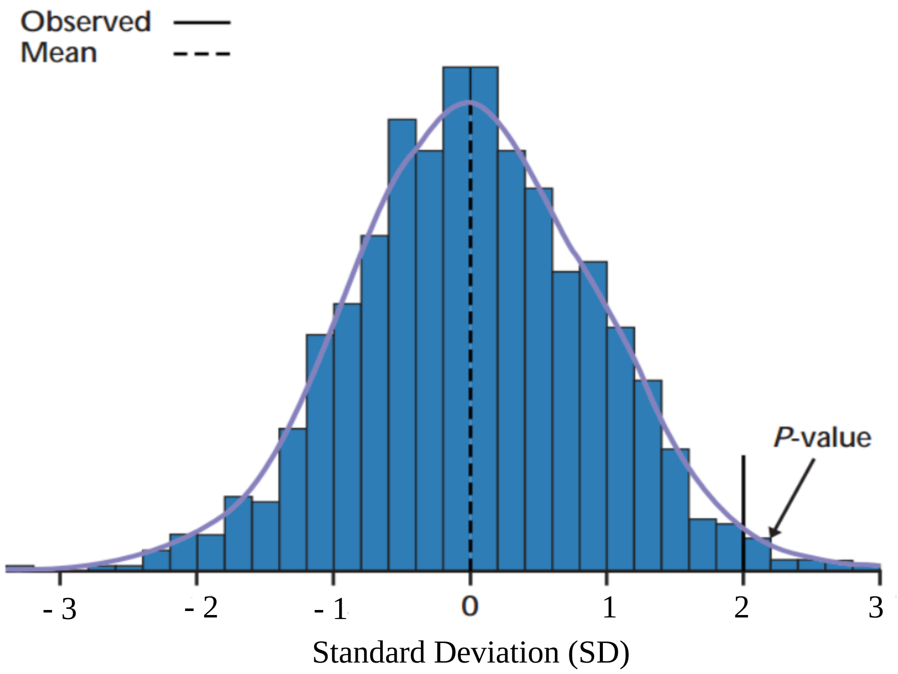



**Figure 5.13: The permutation distribution and p-value of a hypothetical study adapted from Hesterberg et al. (2003). The permutation distribution of the test statistic (difference of the mean scores between two groups) and the observed value located at 2SD above the mean.**

The decision rule regarding the state of the null hypothesis is then based on whether the original obtained test statistic is relatively rare or relatively common in the permutation distribution of the statistic (Edgington, 1995; Good, 1994; Hayes, 1998; Hesterberg et al., 2003). To apply a chance model, the permutation test calculates the number of outcomes of a specified test statistic that would have yielded as extreme a result as the one actually obtained. When the number is small and extreme, the conclusion would be to either accept that chance has had an unlikely effect and that the difference reflects noise, or that the effect of the treatment is real. Like the parametric approach, it is conventional to reject the first option in favour of the latter if the number represents less than 5% of the possible outcomes (Anderson, 2001; Edgington, 1966, 1995; Fisher, 1935; Mewhort, 2005; Smythe & Wei, 1983).

The rank-based nonparametric tests could be a potential alternative when parametric assumptions are strongly violated. However, these tests are less efficient and they lack sensitivity to real treatment effects in small-n studies (Siegel & Castellan, 1988; Todman & Dugard, 2001) because information is discarded when scores are transformed to ranks, and because the statistical tables for rank tests are based on rearrangements of ranks with no tied ranks. Therefore, the probabilities generated are only approximately valid when there are many tied ranks in the data (Edgington, 1995). The permutation tests do not discard any information in the data by transforming to ranks, thereby preserving power and efficiency (Pohlmann et al., 2002; Siegel & Castellan, 1988).

Although the permutation test does not rely on parametric assumptions, its principal assumption is that the participants are randomly assigned to groups and, embedded in this is the assumption of exchangeability of units under the null hypothesis (Anderson, 2001; Edgington, 1995; Fisher, 1935; Kempthorne, 1955; Still & White, 1981). In other words, when the treatment has no effect on the scores of the outcome measures (i.e., the null hypothesis is true), these scores could have occurred in any of the experimental groups. In deciding whether a set of data is exchangeable, Good (1994) posed the question that if under the null hypothesis of no difference among the various experimental or survey groups, can the labels on the observations be exchanged without affecting the results? Hayes (1996) proposed that to demonstrate exchangeability, there should be homoscedasticity (i.e., equality of variance) and independence of observations in at least one variable. The data set in the present study meets the criteria of homoscedasticity and independence of observations. Homoscedasticity was tested using the Koenker-Basset test.

Additionally, like the parametric statistics, the results of the permutation tests can only be generalised to the population if the sample was randomly selected from the population. However, random sampling is often unrealistic in behavioural research where people are the participants in experiments. In the absence of random sampling, the permutation test assesses the association between the two variables in the sample, yet the generalizability or external validity needs to be achieved by repeating the experiment in other contexts (Edgington, 1995; Kempthorne, 1955; Todman & Dugard, 2001).

### 5.11.4 Effect size and its confidence interval

Effect size estimates will be reported for all comparisons in accordance with the guidelines for reporting RCT (American Psychological Association, 2010; Moher et al., 2010; Schuele & Justice, 2006; Schulza, Altmanb, & Moher, 2010). Effect size quantifies the difference between two groups by focusing on the size of the difference independent of the sample size. It provides useful information for detecting the presence of a Type II error, which could be due to a small effect size, high within-population variability, and a small sample size (Aberson, 2002; Acion, Peterson, Temple, & Arndt, 2006; Colegrave & Ruxton, 2003; Kraemer et al., 2003). Additionally, the reporting of effect sizes facilitates comparison across different studies which are necessary for meta-analysis (Cumming, Fidler, & Lai, 2012).

The non-parametric Vargha-Delaney A (Vargha & Delaney, 2000) was used as the effect size measure in this study. This is because many of the routinely used effect size measures (e.g., Cohen’s d, r and $ŋ^2$) are predicated on parametric assumptions. They may lead to biased conclusions if these underlying assumptions are violated (Erceg-Hurn & Mirosevich, 2008; Grissom & Kim, 2001). The Vargha-Delaney A, also known as the area under the Receiver Operating Characteristic curve, is robust to the violation of parametric assumptions (Acion et al., 2006; Kraemer et al., 2003). Details of how it is derived can be found in Vargha and Delaney (2000).

The A statistic provides an estimate of clinical significance (Acion et al., 2006). It represents the probability that a randomly selected participant in the treatment group has a better result than one in the comparison group. It has a range of zero to 1. A value of 0.50 indicates no difference; that is, the probability that a randomly selected participant in the treatment group has better performance than the comparison group is 50%, merely by chance. Values between 0.5 and 1.0 indicate increasingly large effect sizes where the treatment group shows better performance. For instance, an A value of 0.83 indicates that 83% of the time, a random selected participant in the treatment group will have a better outcome than one in the comparison group. On the other hand, values between 0.5 and 0.0 indicate increasingly large effect sizes when the comparison group shows a better performance. For example, an A value of 0.23 would indicate that 23% of the time, the participant in the treatment group would have a better result, or in other words, there was a 77% chance that the participant in the comparison group would have a better result (Vargha & Delaney, 2000). Based on the guidelines put forward by Vargha and Delaney (2000), an A statistic greater than 0.64 or less than 0.36 indicates a medium to large effect size.

The recent guidelines for reporting RCTs also emphasise the reporting of confidence intervals around effect size estimates (American Psychological Association, 2010; Moher et al., 2010; Schulza et al., 2010), because the confidence interval quantifies the margin for error and precision of the estimate. It shows the range within which the true treatment effect is likely to fall (Davis & Crombie, 2010). It can also provide an estimation of its statistical significance. For instance, a 95% confidence interval may provide the equivalent of a significance level of 5% ($\alpha = 0.05$). It represents the amount of variation in the estimate if one were to repeat the experiment many times with new samples of the same size. If the confidence interval includes an A value that indicates no effect (i.e., A = 0.50), then one must conclude that the result is not statistically significant. On the other hand, when A = 0.50 is outside of the range of the confidence interval, then it is considered to be statistically significant at $\alpha = 0.05$ (Coe, 2002). Hence, in this study, the criteria for a significant effect size was determined to be an A statistic greater than 0.64, or less than 0.36, that has a 95% confidence interval that excludes A = 0.50.

### 5.11.5 Procedure of statistical analysis

The steps of the statistical analysis are as follows. Firstly, the pre-intervention profiles of the groups were compared to determine whether the groups were similar in terms of baseline performance for age, non-verbal IQ, phonological awareness, word reading, receptive vocabulary, receptive grammar, executive control and FD. Furthermore, the data concerning the amount of intervention received by the groups was considered and any differences between the groups explored, particularly because the frequency and duration of the intervention sessions that were undertaken by each intervention group could potentially have an impact on the outcome measures. Therefore, it is important to establish whether the overall amount (frequency and duration) of the intervention was the same across the three intervention groups.

Subsequently, the results related to the specific Research Questions will be presented in four sections. Firstly, the intervention-specific effect of the FD intervention and its maintenance were explored (Research Questions A.1 and A.2 found in Section 5.2). The results of the FD intervention specific measure were evaluated across the entire sample over the duration of the study to test whether there were significant main effects of time, group, and interaction. Subsequently, between-group analyses were conducted between the intervention group (i.e., the FD group) and the no intervention groups during Phase 1 of the study (i.e., the PP and CON groups) to investigate for differential intervention effectiveness that was specific to Phase 1. The results of the FD-PP group were also compared with the VD-PP group to investigate whether any observed effects were specific to the FD intervention. Additionally, within-group comparisons of the Ax2 and Ax4 results of the FD intervention-specific measure for the FD-PP group were conducted to see if there were any significant changes in the score after the FD intervention had ceased.

Secondly, Research Questions B.1 and B.2 (see Section 5.2) were investigated to examine the intervention-specific effect of the PP intervention and its maintenance effect. The results of the intervention-specific measure of the PP intervention were evaluated for significant main effects of time, group, and interaction. Subsequently, between-group analyses between the FD-PP, VD-PP, and PP groups were compared to the CON group to investigate for differential effectiveness of the intervention specific to Phase 2 of the study. Additionally, within-group comparisons of the PP group's results after the PP intervention were made to investigate whether there were any significant changes during the maintenance phase between Ax3 and Ax4.

Thirdly, the generalisation effects of the FD intervention and the PP intervention were investigated (Research Questions C.1 and C.2). The within-task generalisation of the two interventions was explored using a similar analytical approach as described above. Additionally, the results of the reading and receptive language measures of the entire sample over the duration of the study were tested for main effects of time, group, and the interaction between time and group. Subsequently, between-group analyses specific to Phase 1 and Phase 2 of the study were conducted to evaluate the generalisation effect of the FD intervention and the PP intervention respectively. The between-group analyses following the same procedure described above were used, starting with a comparison of the results of the intervention groups with controls to evaluate the intervention effects.

Finally, the effects that the prior FD intervention might have on PP intervention outcomes were explored for the measures related to the PP intervention (Research Question D.1). These were: the PP Intervention Test, the phonological awareness subtests of the CTOPP, and the ALNLRAC. The analyses were conducted by comparing the intervention outcomes of the FD-PP and PP groups to test whether any measured improvements were greater with prior FD intervention. Finally, comparisons were made between the FD-PP group and the VD-PP group to investigate whether any of the observed effects were specific to the FD intervention or if they were due to intensive exposure to a computer intervention program (Research Question D. 2).

### 5.11.6 Software tools for the statistical analyses

IBM SPSS Statistics (2010) was used for descriptive statistics and graph generation. Three other software tools were used for the data analysis: 1) PERMANOVA+ add-on for PRIMER 6 (Anderson, Gorley, & Clarke, 2008) was used to perform permutational ANOVAs with repeated measures; 2) the Package Perm of the R statistical software (R Development Core Team, 2011) developed by Fay and Shaw (2010), was used to perform two sample permutation tests; and 3) the Package pROC (Robin et al., 2011) of the R statistical software was used to calculate Vargha-Delaney A for effect size and its confidence interval.

# 6 STUDY 2: RESULTS AND DISCUSSION

The results of Study 2 are presented in this chapter. The pre-intervention profiles of the groups and the results of the comparisons of the amount of intervention received by the two groups are presented in Section 6.1 and 6.2. Results concerning the intervention-specific effect of the FD intervention and its maintenance are presented in Section 6.3 (Research Questions A.1 and A.2 found in Section 5.2) and those of the PP intervention and its maintenance are presented in Section 6.4 (Research Question B.1 and B.2 in Section 5.2). In Section 6.5, the generalisation effects of the FD intervention and PP intervention will be reported (Research Questions C.1 and C.2), firstly, with respect to the within-task generalisation of the two interventions, and subsequently, the generalisation to word reading and language. In Section 6.6, the effects that prior FD might have on PP intervention outcomes were explored for the measures related to the PP intervention (Research Question D.1). Finally, comparisons were made between the FD-PP group and the VD-PP group to investigate whether any of the observed effects were specific to the FD intervention or if they were due to intensive exposure to a computer intervention program (Research Question D. 2).

## 6.1 Pre-intervention Profiles of the Groups

The pre-intervention profiles of the groups were compared with respect to: 1) age; 2) nonverbal intelligence, as measured by the Ravens Coloured Progressive Matrix, RCPM; 3) vocabulary, as measured by the PPVT-4; 4) receptive grammar, as measured by the TROG; 5) executive control, as measured by Simon’s Arrow Task, SAT; 6) FD ability, as measured by the SoundsPod; and 7) phonological awareness ability, as measured by the Phonological Awareness Composite Score of the CTOPP, CTOPP-PA-CS (see Sections 3.9 and 3.10 for details of the above assessments)[17]. Table 6.1 presents the mean and SD of the scores for each of the above measures of the individual groups.

[17] Standard scores and composite standard scores of the above assessments were used in STUDY 2 as opposed to the raw scores and the composite raw scores used in STUDY 1. This was because the two groups in STUDY 1 were age-

**Table 6.1: Age, non-verbal intelligence, receptive vocabulary, sentence comprehension, executive control, FD ability, and phonological awareness of the four groups at Ax1.**

| | | Groups | | | |
|---|---|---|---|---|---|
| | | FD-PP (n=5) | VD-PP (n=6) | PP (n=4) | CON (n=5) |
| **Age (Months)** | Mean | 99.20 | 104.17 | 98.75 | 104.40 |
| | SD | 6.50 | 9.52 | 6.29 | 9.84 |
| **RCPM-SS** | Mean | 108.96 | 93.73 | 103.81 | 96.75 |
| | SD | 12.58 | 8.88 | 11.45 | 14.33 |
| **PPVT-SS** | Mean | 98.00 | 105.00 | 94.25 | 100.40 |
| | SD | 18.07 | 11.83 | 12.69 | 7.89 |
| **TROG-SS** | Mean | 91.00 | 89.33 | 89.00 | 93.60 |
| | SD | 12.61 | 8.62 | 8.04 | 16.56 |
| **SAT-IC-RT (sec)** | Mean | 992.95 | 898.76 | 810.87 | 886.92 |
| | SD | 226.63 | 274.81 | 86.82 | 115.07 |
| **FD-SOUND-TS (Hz)** | Mean | 177.45 | 148.54 | 164.61 | 132.48 |
| | SD | 28.73 | 30.20 | 62.65 | 63.62 |
| **CTOPP-PA-CS** | Mean | 91.60 | 86.00 | 82.75 | 88.60 |
| | SD | 12.62 | 4.90 | 12.58 | 5.77 |

KEY: RCPM-SS = the Ravens Coloured Progressive Matrix standard score; PPVT-SS = the Peabody Picture Vocabulary Test (4$^{th}$ Ed) standard score, TROG-SS = the Test of Reception of Grammar standard score; SAT-IC-RT = the mean reaction time of conflict-incongruent condition of the Simon Arrow Task; FD-SOUND-TS = the FD threshold score of the FD Intervention Specific Test, the SoundsPod; CTOPP-PA-CS = the Comprehensive Test of Phonological Processing Phonological Awareness Composite Score

Multi-group comparisons using a permutation one-way ANOVA showed that the groups did not differ significantly on all initial assessments. The p-values ranged from $p$ = 0.208 to $p$ = 0.934 (see Table 6.2). The permutation approach was used for hypothesis testing in this study instead of the more routinely used parametric or rank-based non-parametric tests. See Section 5.11.3 for the rationale of using the permutation test and a discussion of the permutation approach.

matched but the groups in STUDY 2 were not, although there were no significant differences between the ages of the groups in STUDY 2.

**Table 6.2: Result of the permutational one-way ANOVAs for group differences for age, non-verbal intelligence (RCPM-SS), receptive vocabulary (PPVT-4), sentence comprehension (TROG-SS), executive control (SAT-IC-RT), FD (FD-SOUND-TS) and phonological awareness (CTOPP-PA-CS) at Ax1**

| | *p*-value | 95% CI | Sig. at α = 0.05 |
|---|---|---|---|
| **Age** | $F(3, 16) = 0.64$, $p = 0.577$ | 0.548 – 0.629 | n.s. |
| **RCPM-SS** | $F\ (3, 16) = 1.83$, $p = 0.185$ | 0.175 – 0.242 | n.s. |
| **PPVT-SS** | $F\ (3, 16) = 0.64$, $p = 0.587$ | 0.595 – 0.675 | n.s. |
| **TROG-SS** | $F\ (3, 16) = 0.209$, $p = 0.904$ | 0.911 – 0.953 | n.s. |
| **SAT-IC-RT** | $F\ (3, 16) = 0.61$, $p = 0.608$ | 0.570 – 0.650 | n.s. |
| **FD-SOUND-TS** | $F\ (3, 16) = 0.85$, $p = 0.498$ | 0.454 – 0.537 | n.s. |
| **CTOPP-PA-CS** | $F\ (3, 16) = 0.85$, $p = 0.503$ | 0.527 – 0.609 | n.s. |

## 6.2 Amount of Intervention

During Phase 1 of the study, the FD-PP and VD-PP groups were given identical instructions regarding the amount of intervention to be undertaken, i.e., four intervention sessions per week for six weeks. Participants of these two groups were to engage in the training task five times in each session, and were instructed "*to play the game five times*". Each session lasted approximately 20 minutes based on previous research using the same intervention program (McArthur et al., 2008).

The mean number of games played was 121 (SD = 30.50) in the FD-PP group and 132 (SD = 8.81) in the VD-PP group, $p = 0.460$. The total mean duration of the training (i.e., the time that the groups spend undertaken the training) was 389.50 minutes (SD = 118.18) for the FD-PP group and 600.36 minutes (SD = 106.45) for the VD-PP group. The permutational t-test showed that there was no significant difference between the mean total number of games completed by the two groups ($p = 0.460$), but the mean duration involved in the training was significantly different ($p = 0.024$). A review of the training records data indicated that, on average, the participants in the VD-PP group required a longer duration to complete one (each) single game of the training task. Therefore, despite being engaged with the training task for approximately the same number of runs, the VD-PP group was engaged with the task for a longer duration. The variation in the amount of intervention that both groups undertook during Phase 1 of the study was taken into consideration when interpreting the findings of the study (see Section 6.7.1.1). For instance, if the VD-PP group was found to show significantly greater improvement than the FD-PP intervention group, then this could potentially be (at least partially) attributed to the longer duration of the VD intervention.

The FD-PP, VD-PP, and PP groups all received the PP intervention during Phase 2 of the study. The same instruction was given to the three groups, which was to engage in the training tasks for 20 minutes a day, four days per week for six weeks. The total mean duration of the training period was 446.45 minutes (SD = 116.55) for the FD-PP group, 415.40 minutes (SD = 63.09) for the VD-PP group, and 499.19 minutes (SD = 163.01) for the PP group. The permutational one-way ANOVA showed that there were no significant differences in the duration of training of the individual groups ($p = 0.529$), as such, all three groups that undertook PP intervention had spent a similar amount of time on the PP intervention tasks.

In summary, the FD-PP group and the VD-PP group underwent a similar number of trials of the FD intervention and VD intervention tasks respectively during Phase 1. However, the VD group undertook the VD intervention for a significantly longer period of time. This indicates that it took the children in the VD-PP group longer to complete a single trial of the VD intervention task than those in the FD-PP group with the FD intervention task. This difference was taken into account during the interpretation of results in Section 6.7.1.1. With respect to the PP intervention, the three groups that undertook the PP intervention had spent a similar amount of time on the PP intervention tasks.

## 6.3 The Intervention-Specific Effect of the FD Intervention and its Maintenance

### 6.3.1 Intervention-Specific Effect of the FD Intervention (Research Question A.1)

The FD intervention-specific effect was measured using the threshold score of the SoundsPod (i.e., the FD-SOUND-TS).

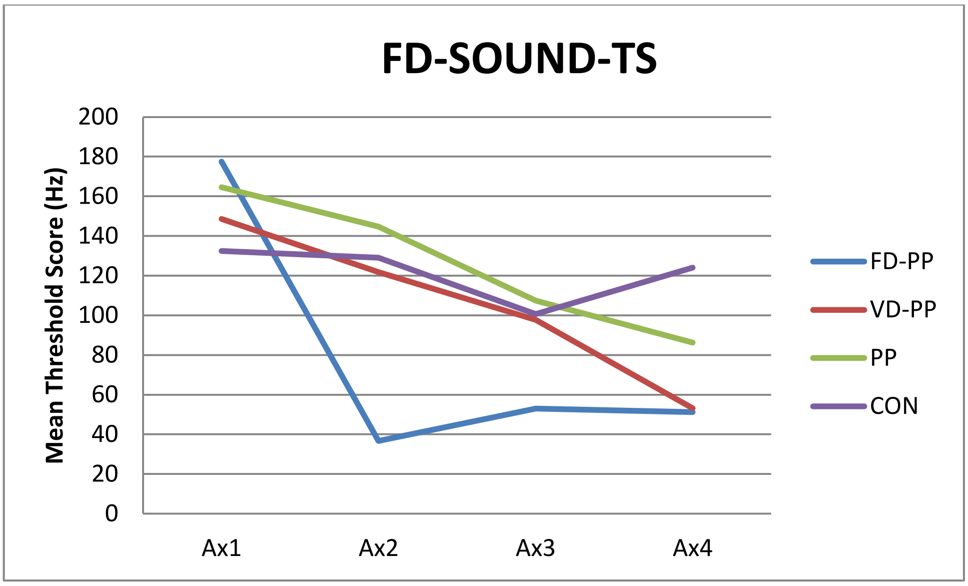



**Figure 6.1: Mean FD-SOUND-TS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

The mean FD-SOUND-TS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.1. The FD-PP group showed a substantial reduction (i.e., a better performance) in the mean FD-SOUND-TS after the FD intervention at Ax2 as compared to their mean score at Ax1. The mean score then remained relatively stable between Ax3 and Ax4, showing a maintenance effect as the group did not receive further FD intervention. The other three groups demonstrated only a gradual decline (i.e., improvement) in their mean FD-SOUND-TS across the four assessments (Ax1-Ax4) with the exception of the CON group who showed poorer performance at Ax4. Summary data for the FD-SOUND-TS of the four groups are presented in Table 6.3.

**Table 6.3: Summary FD-SOUND-TS data of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

| | **FD-PP** | | **VD-PP** | | **PP** | | **CON** | |
|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD |
| **Ax1** | 177.45 | 28.73 | 148.54 | 30.20 | 164.61 | 62.65 | 132.48 | 63.62 |
| **Ax2** | 36.62 | 55.54 | 121.84 | 79.01 | 144.66 | 57.29 | 128.98 | 85.36 |
| **Ax3** | 53.01 | 77.21 | 97.71 | 75.25 | 107.37 | 78.64 | 100.60 | 81.48 |
| **Ax4** | 51.22 | 57.76 | 53.14 | 59.40 | 86.28 | 73.93 | 123.99 | 85.03 |

#### *6.3.1.1 The FD-SOUND-TS of the entire sample over the duration of the study*

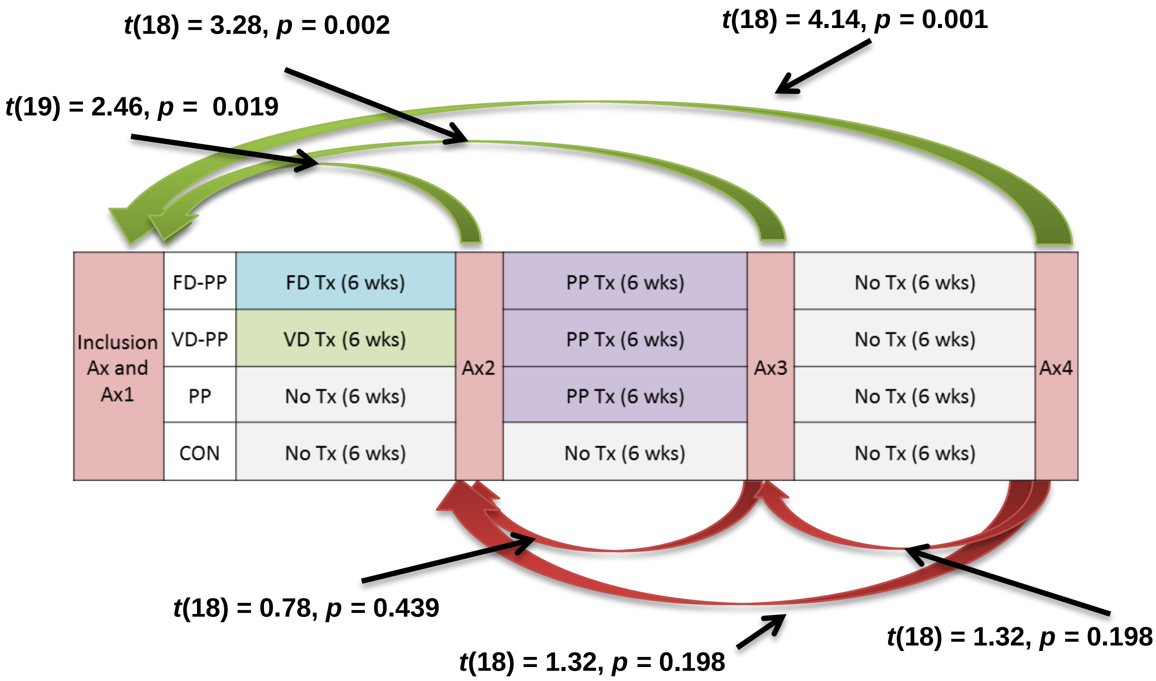



**Figure 6.2: A diagram demonstrating the results of the post hoc pair-wise analyses of the FD-SOUND-TS using the permutational two-tailed *t*-test for the significant time effect found by the permutational ANOVA with repeated measures. The results suggest that the significant reduction in the FD-SOUND-TS over time was mainly observed during Phase 1, and not during Phase 2.**

The result of the permutational ANOVA with repeated measures showed a significant time effect, which indicates a reduction of the FD-SOUND-TS (i.e., better performance) for all groups across the four assessments ($F(3,64) = 5.15$, $p = 0.0039$). Post hoc pair-wise comparisons using the permutational two-tailed *t*-test revealed a significant reduction in the FD-SOUND-TS between Ax1 and Ax2 ($t(19) = 2.46$, $p = 0.019$), Ax1 and Ax3 ($t(18) = 3.28$, $p = 0.002$), and Ax1 and Ax4 ($t(18) = 4.14$, $p = 0.001$). However, there were no significant differences between Ax2 and Ax3 ($t(18) = 0.78$, $p = 0.439$), Ax2 and Ax4 ($t(18) = 1.32$, $p = 0.198$), and Ax3 and Ax4 ($t(18) = 0.48$, $p = 0.628$). This suggests that the significant reduction in the score over time was mainly observed during Phase 1, and not during Phase 2 as expected (see Figure 6.2). There were no significant main effects for groups ($F(3, 64) = 1.89$, $p = 0.142$) or for interaction ($F(3,64) = 1.06$, $p = 0.402$) over the duration of the study. This shows that there was a reduction in the score across all groups over the study period.

In summary, the FD-SOUND-TS showed a significant time effect which was mainly driven by the changes in the score during Phase 1. However, neither the group effect nor the interaction was significant which indicates that there was an overall reduction in the score across all four groups over the study period. Between-group, intervention-specific differential effectiveness will be further explored in the next section.

#### *6.3.1.2 Between-group analysis for intervention-specific differential effectiveness*

The means of the FD-SOUND-TS of the FD-PP group and the two no-intervention groups in Phase 1, i.e., the PP and CON groups, are highlighted in Figure 6.3. Between-group analyses of the difference score of the FD-SOUND-TS in Phase 1 were conducted to examine the differential effect of the FD and VD interventions during Phase 1.

The results showed that there was a significant reduction in the FD-SOUND-TS of the FD-PP group compared to the PP group ($p$ = 0.016) and the CON group ($p$ = 0.008). The PP and the CON groups were the two groups that received no intervention during this period. The A statistic was calculated for effect size; the largest possible effect size (A = 1.00, 95% CI = 1.00 – 1.00) was found in the comparisons. The A statistic indicates that there was a probability of nearly 100% that a randomly selected participant in the FD-PP group would have shown a larger **reduction** in the FD-SOUND-TS compared to a randomly selected participant from the PP or the CON group. The 95% confidence interval (CI) of A confirmed this finding, suggesting that there is 95% certainty that A would be a score of 1.00 (see Section 5.11.4 for more information on the description and interpretation of the A statistics and the CI of A).

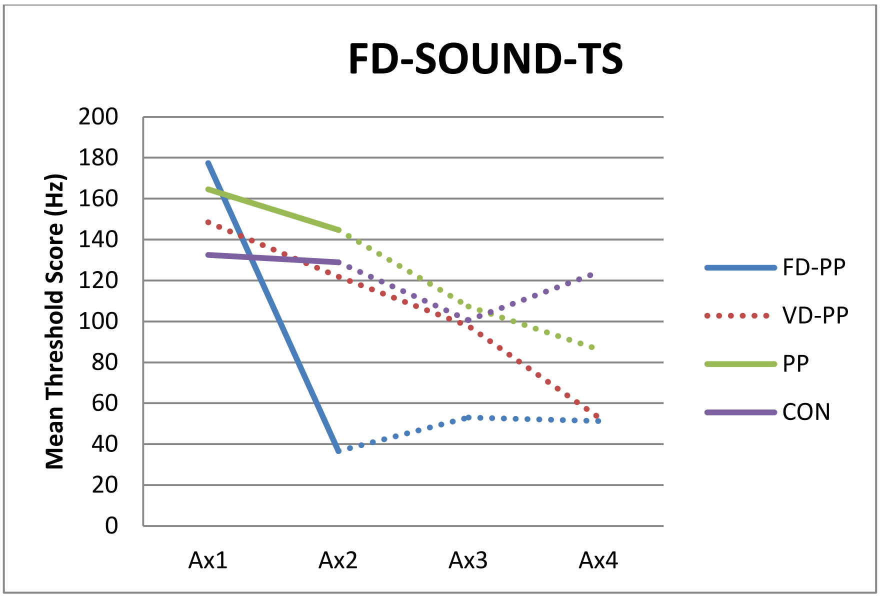



**Figure 6.3: Mean FD-SOUND-TS of the FD-PP group, PP group, and CON group across Ax1 and Ax2 (Phase 1)**

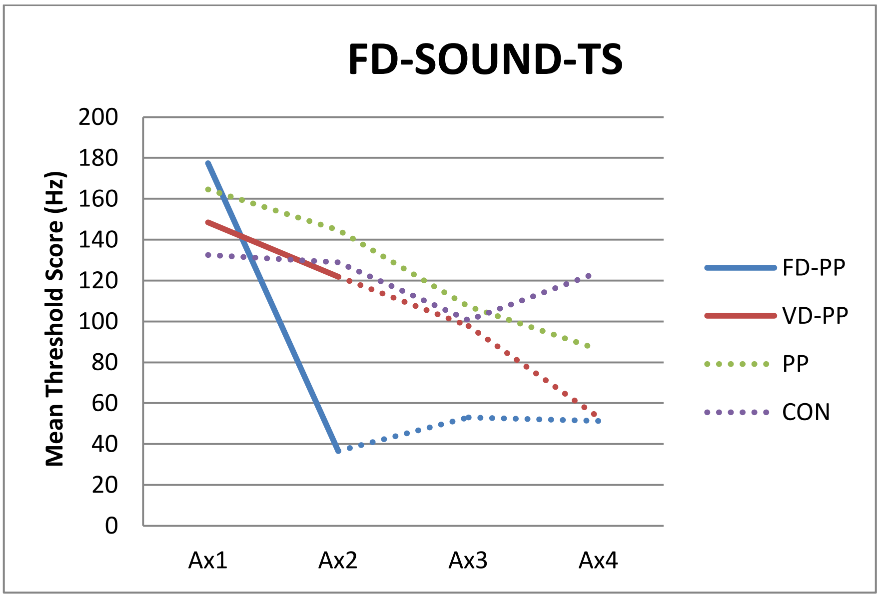



**Figure 6.4: Mean FD-SOUND-TS of the FD-PP group and VD-PP group across Ax1 and Ax2 (Phase2)**

An additional comparison was made between the FD-PP and the VD-PP groups to investigate whether the observed intervention effect in Phase 1 could be an artefact of (general) intensive exposure to a specific computer training program, i.e., whether the observed effect was specific to the FD-PP group or that it was also found in the VD-PP group.

The means of the FD-SOUND-TS of the FD-PP and VD-PP groups during Phase 1 (Ax1-Ax2) are highlighted in Figure 6.4. The FD-PP group showed a significantly greater reduction ($p$ = 0.030) in FD-SOUND-TS than the VD-PP group in Phase 1. The A statistic showed a large ES (A = 0.90, 95% CI = 0.71 – 1.00). In other words, there is a probability of 90% that a randomly selected individual from the FD-PP group will have a larger reduction in the FD-SOUND-TS than a randomly selected individual from the VD-PP group. The 95% CI of A indicates that there is 95% certainty that the ES would be at least a medium to large ES of A > 0.71.

### 6.3.2 Maintenance of the FD intervention-specific effect (Research Question A.2)

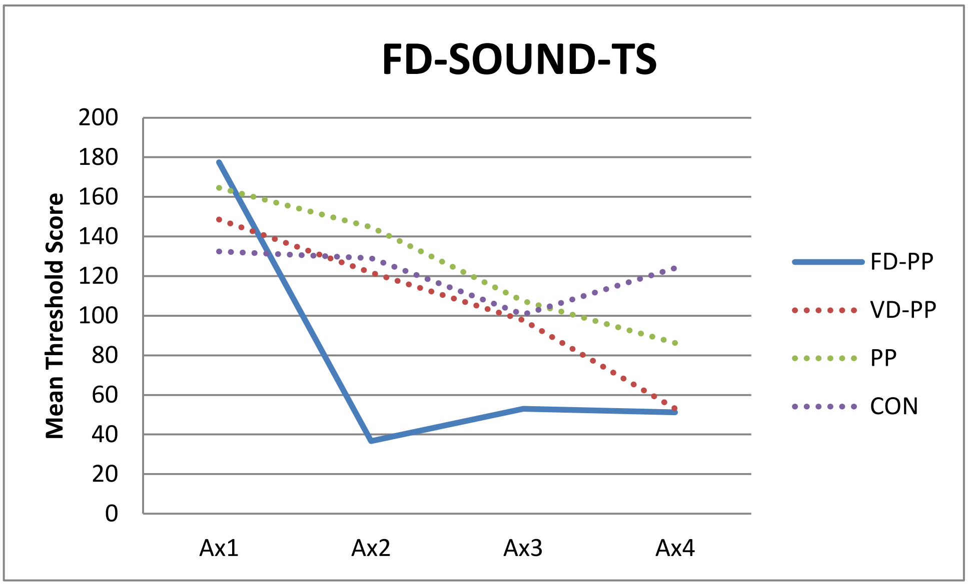



**Figure 6.5: Mean FD-SOUND-TS of the FD-PP group across Ax1, Ax2, Ax3, and Ax4**

The means of the FD-SOUND-TS of the FD-PP group across the study period are highlighted in Figure 6.5. After the substantial reduction in the threshold score in Phase 1 (Ax1-Ax2), there was a slight increase in mean threshold score performance in Phase 2 (Ax2-Ax3); subsequently, the threshold score remained relatively stable during the maintenance phase (Ax3-Ax4). The FD-SOUND-TS was 177.45Hz (SD = 28.73) at Ax1, 36.61 (SD = 55.54) at Ax2, 53.01 (SD = 77.21) at Ax3, and 51.22 (SD = 57.76) at Ax4.

Within-group comparison of the FD-SOUND-TS of the FD-PP group across Ax2 and Ax4 showed that there was no significant difference between the FD-SOUND-TS at Ax2 and Ax4 ($p$ = 0.381). The A statistic showed a large, yet statistically non-significant effect size (A = 0.81, 95% CI of A = 0.47 – 1.00). Therefore, the results showed that the effect of the FD intervention was maintained.

In summary, the results showed that: (1) FD intervention was effective in reducing the FD threshold score in the FD-PP group; and (2) that this effect was specific to the FD intervention rather than to intensive exposure to a computer training program (Research Question A.1). This effect was maintained throughout the course of the study (Research Question A.2).

## 6.4 The Intervention-Specific Effects of PP Intervention and its Maintenance Effect

### 6.4.1 Intervention-specific effect of PP Intervention (Research Question B.1)

The intervention-specific effect of the PP Intervention was measured by the performance on the PP Intervention Test, which involved the reading and writing of the target words used in the PP intervention. The obtained accuracy score is referred to as the PP Intervention Literacy Score (PP-I-LS).

The means of the PP-I-LS of the four groups during Phase 2 and the maintenance phase (Ax2, Ax3, and Ax4[18]) are displayed in Figure 6.6. All intervention groups (i.e., the FD-PP, VD-PP, and PP groups) demonstrated varying degrees of improvement during Phase 2 (Ax2-Ax3). The VD-PP and the PP groups demonstrated greater increase in the mean PP-I-LS than the FD-PP group. Additionally, the PP-I-LS of these three groups remained relatively similar across the maintenance phase (i.e., across Ax3 and Ax4). The CON group showed the highest PP-I-LS at Ax2 and this

[18] This measure was not administered during Ax1 due to time constraints. Many tests were administered in Ax1. In addition to the tests administered in Ax2 to Ax4, inclusion testing was also conducted at Ax1which included hearing screening, visual screening, non-verbal intelligence, and executive control testing. On average, Ax1 took approximately 3 hours to complete, while the other three assessments took approximately 2 hours. In view of the possible risk of confounding the Ax1 results due to fatigue, a decision was made to reduce the number of assessments conducted at Ax1, and hence, the PP Intervention Test was not conducted during Ax1.

remained relatively similar across the three assessment sessions. The summary data of the PP-I-LS of the four groups are presented in Table 6.4.

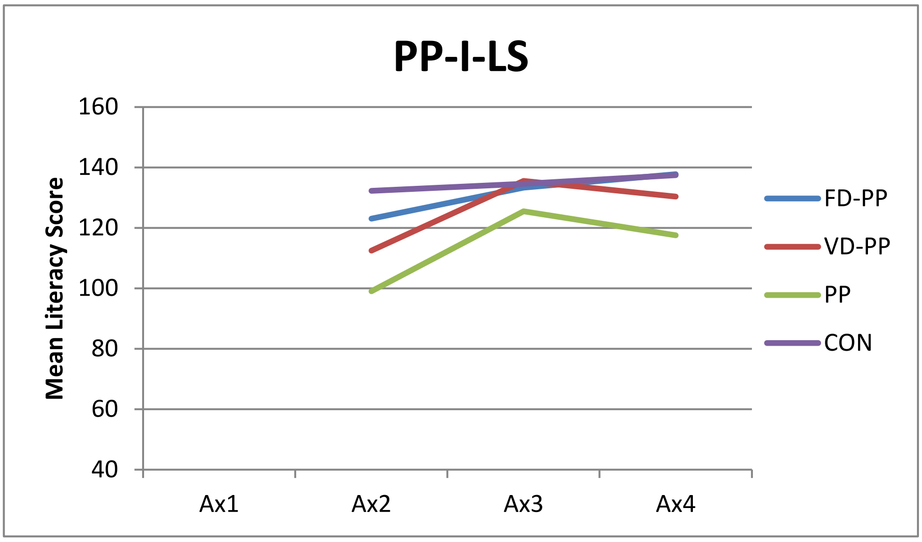



**Figure 6.6: Mean PP-I-LS of the FD-PP group, VD-PP group, PP group, and CON group across Ax2, Ax3, and Ax4**

**Table 6.4: Summary PP-I-LS data of the FD-PP group, VD-PP group, PP group, and CON group across Ax2, Ax3, and Ax4**

| | **FD-PP** | | **VD-PP** | | **PP** | | **CON** | |
|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD |
| **Ax2** | 123.00 | 22.11 | 112.50 | 26.28 | 99.00 | 31.28 | 132.20 | 13.16 |
| **Ax3** | 133.25 | 18.25 | 135.50 | 17.21 | 125.50 | 23.01 | 134.60 | 13.26 |
| **Ax4** | 137.75 | 13.45 | 130.33 | 23.42 | 117.50 | 27.31 | 137.40 | 11.39 |

### *6.4.1.1 The PP-I-LS of the entire sample over the duration of the study*

The results of the permutational ANOVA with repeated measures showed a significant overall main effect for time ($F(2, 48) = 3.51$, $p = 0.037$). Post hoc pairwise comparisons showed a significant improvement in the score across Phase 2 (Ax2-Ax3) ($t(18)= 2.33$, $p = 0.027$) and between Ax2 and Ax4 ($t(18) = 2.05$, $p = 0.05$). No significant changes were found during the Maintenance Phase (Ax3-Ax4) ($t(18) = 0.29$, $p = 0.784$), see Figure 6.7. There was no significant main effect for group $F(3, 48) = 2.64$ ($p = 0.058$) or interaction ($F(6, 48) = 0.40$, $p = 0.870$).

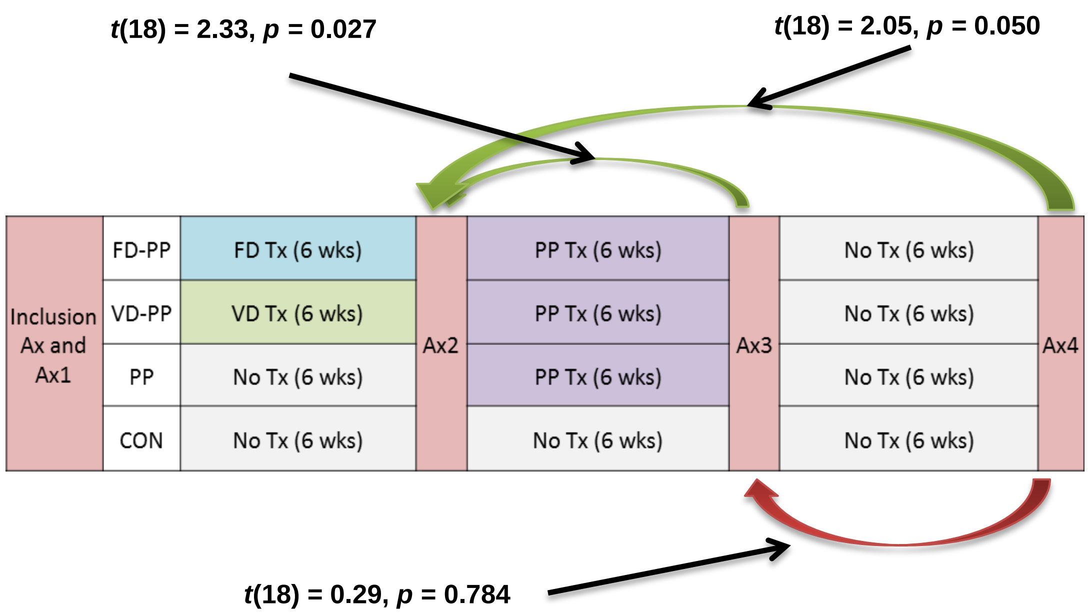



**Figure 6.7: A diagram demonstrating the results of the post hoc pair-wise analyses of the PP-I-LS using the permutational two-tailed *t*-test for the significant time effect found by the permutational ANOVA with repeated measures. The results suggest that the significant reduction in the PP-I-LS over time was mainly observed during Phase 2 and not during the Maintenance Phase.**

### *6.4.1.2 Between-group analysis for differential intervention effectiveness*

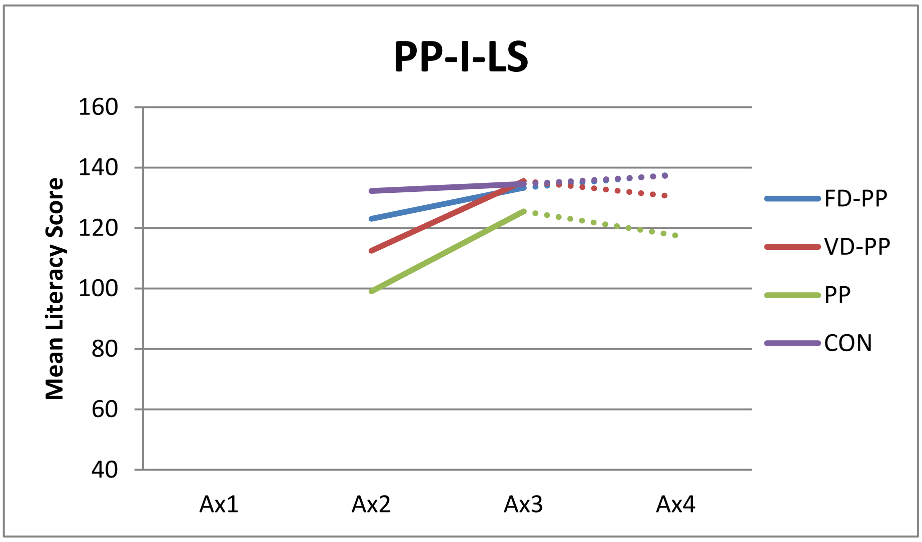



**Figure 6.8: Mean PP-I-LS of the FD-PP group, VD-PP group, PP group, and CON group across Ax2 and Ax3 (Phase 2)**

The mean PP-I-LS scores of the four groups in Phase 2 (Ax2-Ax3) are highlighted in Figure 6.8. Between-group analyses were conducted to examine the PP-I-LS difference score across Phase 2 of the groups that underwent the PP intervention (i.e., the PP, FD-PP, and VD-PP groups) and the CON group. Significant improvements with substantial effect sizes were found in all three intervention groups compared to the CON group (PP vs. CON: $p$ = 0.016, A = 1.00, 95% CI = 1.00 – 1.00; FD-PP vs. CON: $p$ = 0.032, A = 0.95, 95% CI = 0.81 – 1.00; and VD-PP vs. CON: $p$ = 0.004, A= 1.00, 95% CI of A = 1.00 – 1.00). To examine whether these results were due to the lower pre-intervention score of the intervention groups, a permutational one-way ANOVA was conducted on the pre-intervention (i.e., Ax2) PP-I-LS of the four groups. No significant differences were found ($F(3,16) = 1.64$, $p$ = 0.213). Therefore, these results suggest that the PP intervention resulted in significant improvements in the PP Intervention-Specific Literacy Score (Research Question B.1) for all groups that undertook the PP intervention.

### 6.4.2 Maintenance of the PP intervention-specific effect (Research Question B.2)

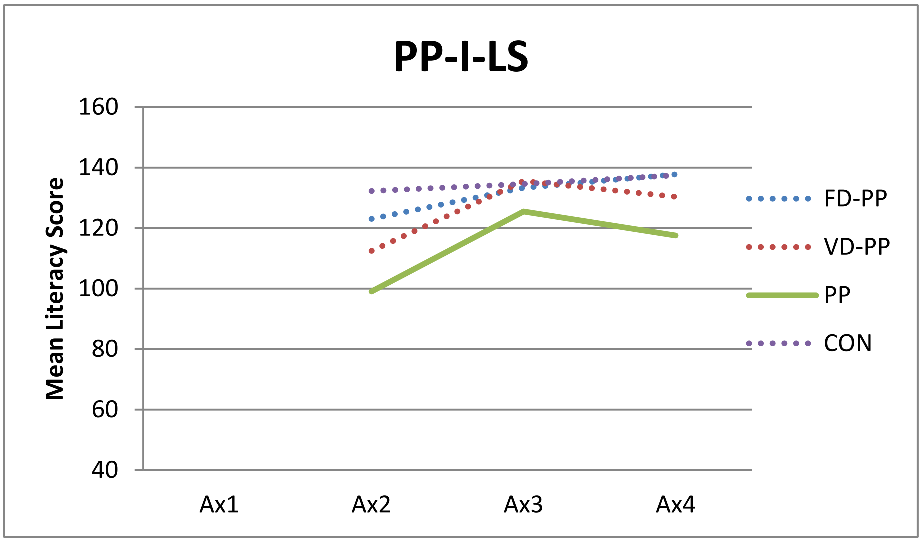



**Figure 6.9: Mean PP-I-LS of the PP group across Ax1, Ax2, Ax3, and Ax4**

The means of the PP-I-LS of the PP group across Phase 2 and the Maintenance Phase (Ax3-Ax4) are highlighted in Figure 6.9. There was an increase in the mean score in Phase 2 (Ax2-Ax3), which was followed by a slight reduction in the Maintenance Phase (Ax3-Ax4). In the Maintenance Phase, the PP-I-LS of the PP group were 125.50 (SD = 23.01) and 117.50 (SD = 27.30).

The result of the within-group comparison shows that the reduction in the mean PP-I-LS score between Ax3 and Ax4 was not significant ($p$ = 0.657, A = 0.66, 95% CI = 0.20 – 1.00) and the ES data showed that the ES was not statistically significant (i.e., CI of A included the value of no effect, A = 0.50). Therefore, these results demonstrate that the intervention-specific effect of the PP intervention was maintained (Research Question B.2).

## 6.5 Generalisation of the FD and PP Intervention Effects

### 6.5.1 Within-task generalisation of the FD intervention and the PP intervention (Research Question C.1)

#### *6.5.1.1 Within-task generalisation of FD intervention*

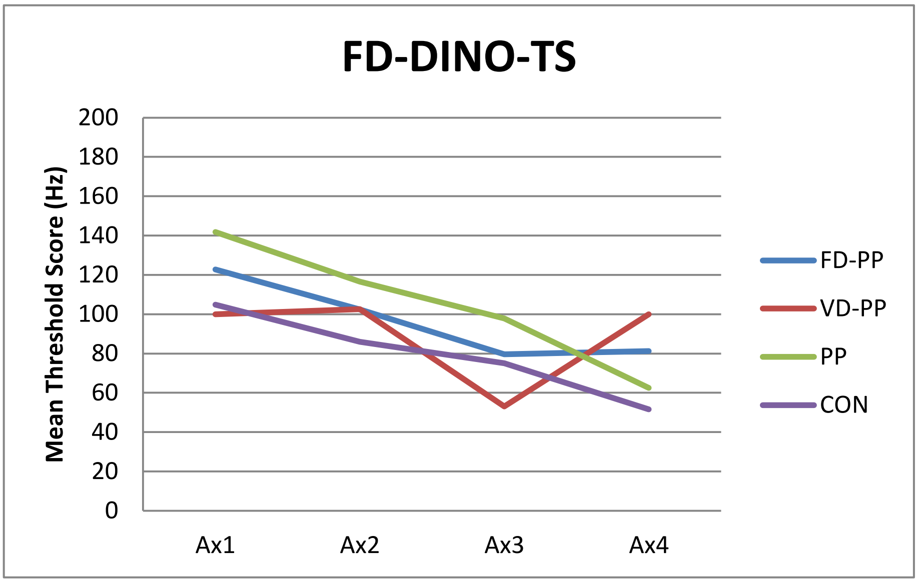



**Figure 6.10: Mean FD-DINO-TS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

Within-task generalisation of the FD intervention was measured by the threshold performance on a different, yet equivalent, task of FD, the Dinosaur Task (FD-DINO-TS).The means of the FD-DINO-TS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.10. Three of the four groups (the FD-PP, PP, and CON groups) demonstrated a gradual reduction (i.e., better performance) in the FD-DINO-TS over the four assessment sessions. However, the FD-DINO-TS of VD-PP group remained stable in Phase 1 (Ax1-Ax2), then declined at Ax3 and was back at base-line level at Ax4. Summary data of the FD-DINO-TS of the four groups are presented in Table 6.5.

**Table 6.5: Summary FD-DINO-TS data of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

| | **FD-PP** | | **VD-PP** | | **PP** | | **CON** | |
|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD |
| **Ax1** | 122.74 | 67.81 | 99.97 | 78.53 | 141.83 | 86.56 | 104.91 | 67.61 |
| **Ax2** | 102.36 | 74.96 | 102.50 | 76.49 | 116.57 | 88.93 | 85.87 | 73.27 |
| **Ax3** | 79.58 | 80.27 | 52.98 | 64.48 | 97.76 | 52.26 | 75.07 | 73.06 |
| **Ax4** | 81.24 | 61.76 | 99.92 | 84.32 | 62.50 | 62.18 | 51.58 | 51.47 |

###### *6.5.1.1.1 FD-DINO-TS of the entire sample over the duration of the study*

The results of the two sample permutation test showed that the FD-DINO-TS of the FD-PP group did not differ significantly across Phase 1 (Ax1-Ax2) ($p$ = 0.603). Additionally, there were no significant differences in the FD-DINO-TS across Phase 1 of the other three groups (VP-PP group: p = 0.959; PP group: p = 0.714; CON group: p = 0.714).

The results of the permutational ANOVA with repeated measures showed that there were no significant main effects for time ($F$(3,64) = 1.61, $p$ = 0.196), group ($F$(3, 64) = 0.44, $p$ = 0.717), or interaction ($F$(9, 64) = 0.29, $p$ = 0.978). This shows that there was no significant difference in the change in performance on the FD-DINO-TS across all groups, across the study period. Therefore, the results demonstrate that there was no within-task generalisation of the FD intervention-specific effect.

#### *6.5.1.2 Within-task generalisation of the PP Intervention*

The within-task generalisation of the PP intervention was measured by the Phonological Awareness Composite Score of the CTOPP (i.e., the CTOPP-PA-CS).

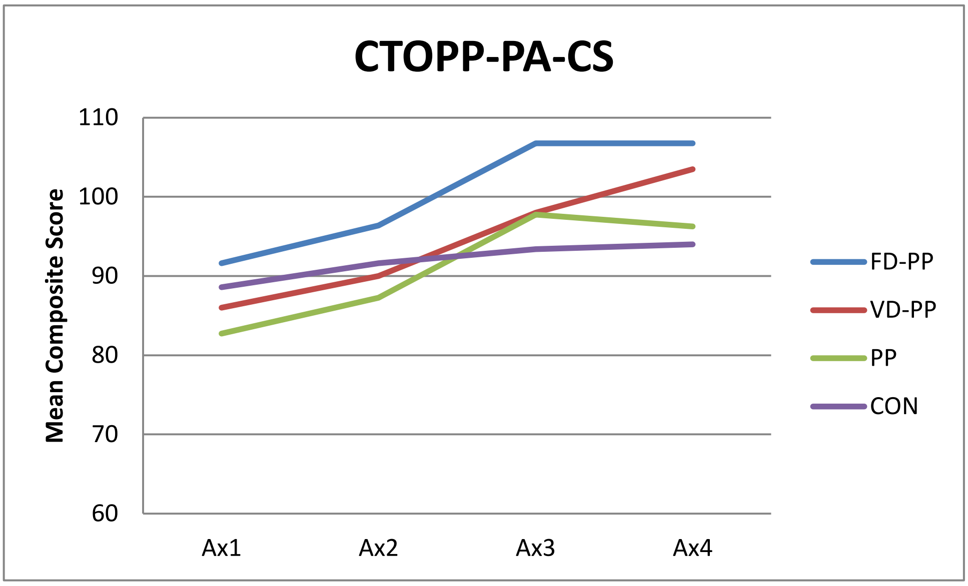



**Figure 6.11: Mean CTOPP-PA-CS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

**Table 6.6: Summary CTOPP-PA-CS data of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

| | FD-PP | | VD-PP | | PP | | CON | |
|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | M | SD |
| **Ax1** | 91.60 | 12.62 | 86.00 | 4.90 | 82.75 | 12.58 | 88.60 | 5.77 |
| **Ax2** | 96.40 | 11.70 | 90.00 | 5.59 | 87.25 | 11.84 | 91.60 | 4.93 |
| **Ax3** | 106.75 | 11.59 | 98.00 | 4.90 | 97.75 | 14.57 | 93.40 | 8.59 |
| **Ax4** | 106.75 | 11.32 | 103.50 | 5.50 | 96.25 | 11.06 | 94.00 | 9.95 |

The means of the CTOPP-PA-CS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.11. The three groups that received the PP intervention all showed an increase in the mean CTOPP-PA-CS in Phase 2 (Ax2-Ax3). The FD-PP and PP groups showed a similar trend in the score across the Maintenance Phase, while the VD-PP group continued to show an increment in the score during the Maintenance Phase. In comparison, the mean CTOPP-PA-CS of the CON group remained relatively stable during the entire study period. Summary CTOPP-PA-CS data of the four groups are presented in Table 6.6. As can be seen, the three groups undergoing the PP intervention all showed an increase of 8-10 points of the CTOPP-PA-CS during Phase 2 (Ax2-Ax3).

*6.5.1.2.1 CTOPP-PA-CS of the entire sample over the duration of the study*

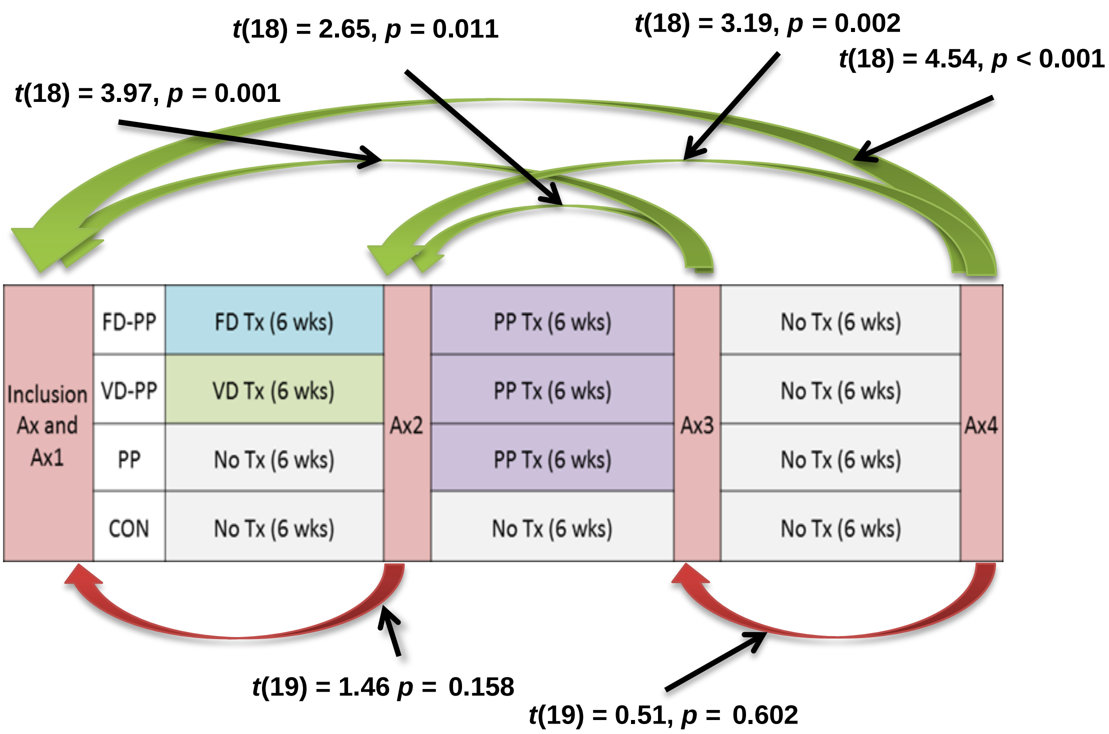



**Figure 6.12: A diagram demonstrating the results of the post hoc pair-wise analyses of the CTOPP-PA-CS using the permutational two-tailed *t*-test for the significant time effect found by the permutational ANOVA with repeated measures. The results suggest that the significant reduction in the CTOPP-PA-CS over time was mainly observed during Phase 2, and not during Phase 1 or the Maintenance Phase.**

The permutational ANOVA with repeated measures showed that there was a significant overall main effect for time ($F(3, 64) = 9.38$, $p < 0.001$). Post hoc pairwise comparisons showed that there were significant changes in the scores between Ax2 and Ax3 ($t(18) = 2.65$, $p = 0.011$), and also between Ax1 and Ax3 ($t(18) = 3.97$, $p = 0.001$), Ax1 and Ax4 ($t(18) = 4.54$, $p = 0.000$), and Ax2 and Ax4 ($t(18) = 3.19$, $p = 0.002$). However, there were no significant differences in the scores during Phase 1 (Ax1-Ax2) ($t(19) = 1.46$, $p = 0.158$) and during the Maintenance Phase (Ax3-

Ax4) ($t(18) = 0.51$, $p = 0.602$), see Figure 6.12. These findings suggest that the significant improvement over time was due to the effects of the PP intervention during Phase 2 (Ax2-Ax3).

There was an overall significant main effect for group ($F(3, 64) = 4.50$, $p = 0.006$). A permutational one-way ANOVA of the CTOPP-PA-CS of the four groups at Ax1 showed that there were no significant differences between the groups at Ax1 ($F(3, 16) = 0.85$, $p = 0.500$). This provides further evidence that the changes in the CTOPP-PA-CS were effects of the PP intervention. Post hoc pairwise comparisons using the permutational two-tailed *t*-test showed that there were significant differences in the change of performance of the FD-PP group and the other three intervention groups over the course of the study (the FD-PP group vs. the VD-PP group: $t(9) = 2.41$, $p = 0.023$; the FD-PP group vs. the PP group: $t(7) = 2.44$, $p = 0.023$; and the FD-PP group vs. the CON group, $t(8) = 3.00$, $p = 0.005$). However, there were no significant differences between the other three groups (the VD-PP group vs. the PP group, $t(8) = 1.25$, $p = 0.228$; the VD-PP group vs. the CON group: $t(9) = 1.65$, $p = 0.228$; and the PP group vs. the CON group, $t(7) = 0.40$, $p = 0.706$). These results indicate that the FD-PP group showed a significantly greater improvement than the other three groups[19]. Nevertheless, there were no significant interaction effects ($F(9, 64) = 0.51$, $p = 0.868$).

*6.5.1.2.2 Between-group analysis for differential intervention effectiveness on the CTOPP-PA-CS*

The means of the CTOPP-PA-CS of the four groups across Ax2 and Ax3 are highlighted in Figure 6.13. Again, between-group analyses of the CTOPP-PA-CS difference scores across Ax2 and Ax3 of the groups that underwent the PP intervention (i.e., the PP, FD-PP, and VD-PP groups) and the CON group were conducted to further examine the effect of the intervention during Phase 2. The results show that not all comparisons reached statistical significance (PP group vs. CON group: $p = 0.079$, A = 0.88, 95% CI of A = 0.61 – 1.00; FD-PP group vs. CON group: $p = 0.063$, A = 0.88,

[19] This has implications for the effect that prior FD intervention has on PP intervention outcomes and will be explored in Section 6.6.

95%, CI of A = 0.61 – 1.00; and VD-PP group vs. CON group: *p* = 0.186, A = 0.84, 95% CI of A = 0.51 – 1.00). Although a relatively large effect size was observed, the CI of A showed a wide interval (A = 0.51 – 1.00) indicating the possibility that the detected effect might be a small ES of A = 0.51.

Overall, the results only provide partial evidence that the effect of PP intervention generalised to another task of phonological awareness. Pairwise comparisons showed that the significant main effect for time was mainly due to the improvement in the CTOPP-PA-CS of the three intervention groups during the PP intervention phase. The main effect for group was largely due to the significant difference in performance of the FD-PP group compared to the other three groups across all four assessment sessions. This suggests a positive effect that prior FD intervention had on the PP intervention outcome for phonological awareness, but it does not provide direct support for the independent, within-task generalisation of the PP intervention. Additionally, pairwise comparisons across intervention Phase 2 showed that the CTOPP-PA-CS of the intervention groups and the CON group failed to reach statistical significance.

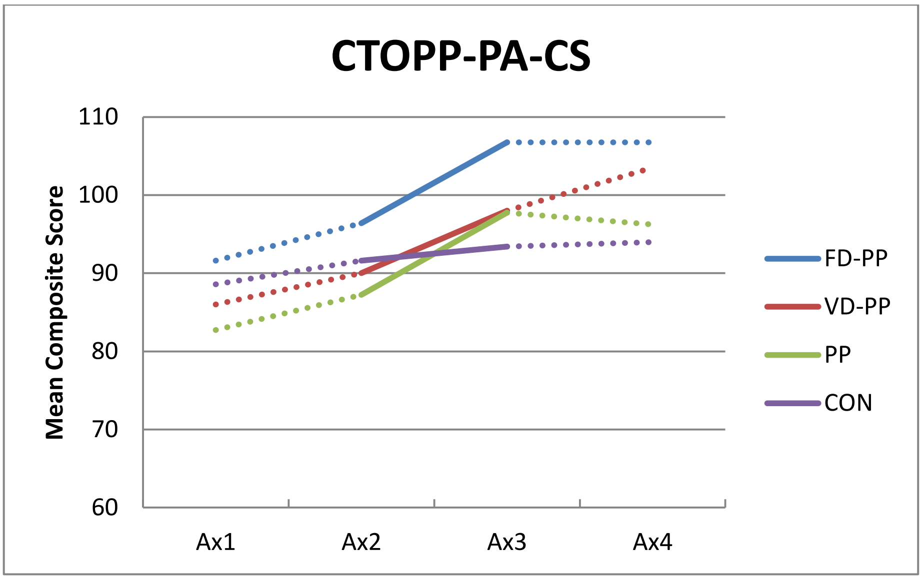



**Figure 6.13: Mean CTOPP-PA-CS of the FD-PP group, VD-PP group, PP group, and CON group across Ax2 and Ax3 (Phase 2)**

## 6.5.2 Generalisation of FD Intervention and PP Intervention effects to Word Reading and language ability (Research Question C.2a)

### *6.5.2.1 Generalisation of FD and PP intervention effects to word reading ability*

The generalisation effects of the FD intervention and the PP intervention to word reading ability was measured by the non-word, irregular word, and regular word reading *z*-scores of the ALNLRAC (i.e., the ALNLRAC-NW-ZC, the ALNLRAC-IW-ZS, and the ALNLRAC-RW-ZS respectively).

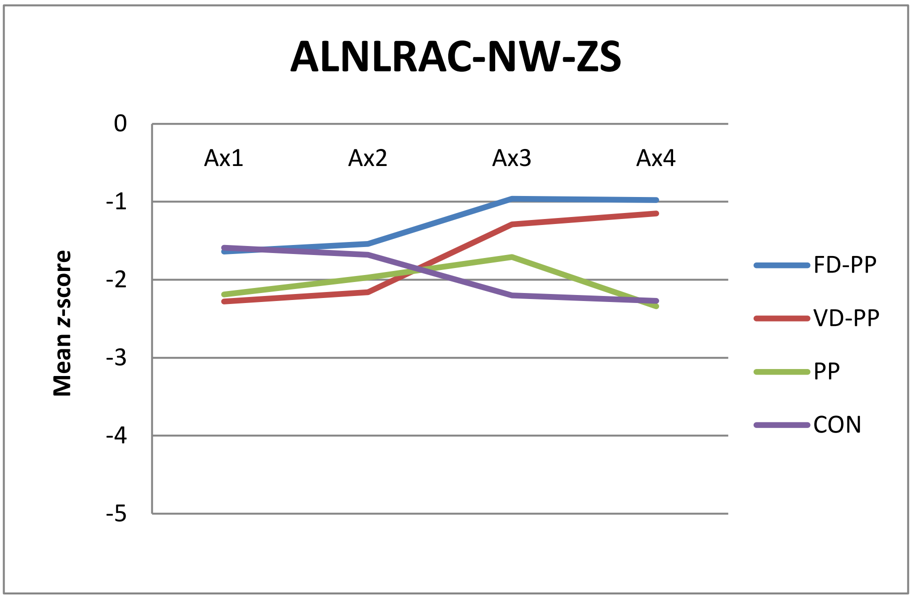



**Figure 6.14: Mean ALNLRAC-NW-ZS of the FD-PP group, VD-PP group, PP group, and the CON group across Ax1, Ax2, Ax3, and Ax4**

The means of the ALNLRAC-NW-ZS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.14. There was no increase in the z-score during Phase 1 (Ax1-Ax2), and the Maintenance Phase (Ax3-Ax4). Increase in the *z*-score was observed in the FD-PP and VD-PP groups in Phase 2 (Ax2-Ax3), which was greater than the increase made by the PP group in Phase 2. The CON group showed a reduction in the *z*-score in Phase 2

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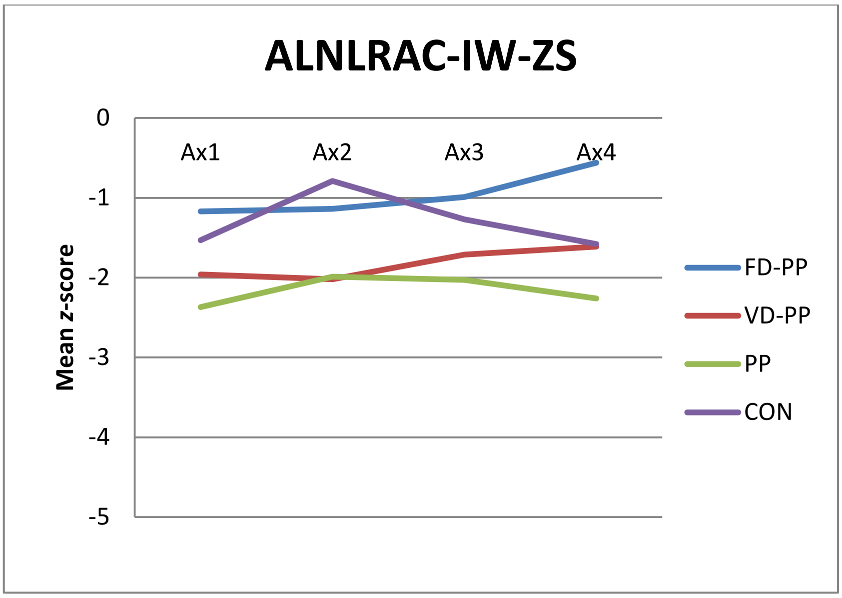


**Figure 6.15: Mean ALNLRAC-IW-ZS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

The mean of the ALNLRAC-IW-ZS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.15. All four groups showed limited variation in the *z*-score across the entire study period, with one exception, namely for the CON group who showed an increase in the mean score at Ax2.

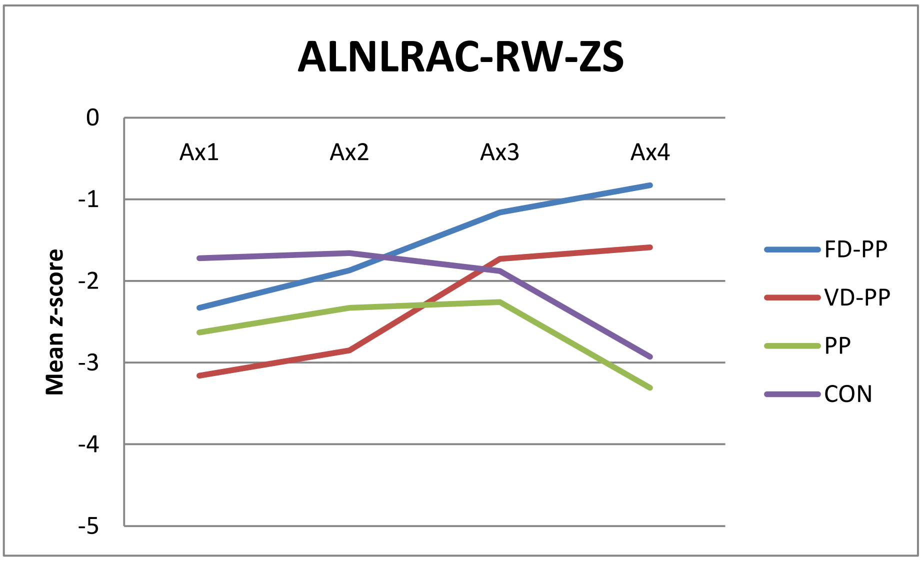


**Figure 6.16: Mean ALNLRAC-RW-ZS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

The means of the ALNLRAC-RW-ZS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.16. Both the FD-PP and VD-PP groups demonstrated increased mean ALNLRAC-RW-ZS during intervention Phase 2 (Ax2-Ax3), whereas there was no improvement in their scores during intervention Phase 1 (Ax1-Ax2), and in the Maintenance Phase (Ax3-Ax4). The PP and CON groups did not show much improvement or decline in the mean ALNLRAC-RW-ZS across the study period. Summary ALNLRAC-NW-ZS, ALNLRAC-RW-ZS, and ALNLRAC-IW-ZS data of the four groups across the study period are presented in Table 6.7.

**Table 6.7: Summary ALNLRAC-NW-ZS, ALNLRAC-IW-ZS, and ALNLRAC-RW-ZS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

| | FD-PP | | VD-PP | | PP | | CON | |
|---|---|---|---|---|---|---|---|---|
| **ALNLRAC-NW-ZS** | M | SD | M | SD | M | SD | M | SD |
| **Ax1** | -1.64 | 1.22 | -2.28 | 0.88 | -2.19 | 0.95 | -1.59 | 1.09 |
| **Ax2** | -1.54 | 1.34 | -2.16 | 0.65 | -1.97 | 0.75 | -1.68 | 1.27 |
| **Ax3** | -0.96 | 1.37 | -1.29 | 0.59 | -1.71 | 0.94 | -2.20 | 1.83 |
| **Ax4** | -0.98 | 1.37 | -1.15 | 0.89 | -2.34 | 0.95 | -2.27 | 1.59 |
| **ALNLRAC-IW-ZS** | | | | | | | | |
| **Ax1** | -1.17 | 0.87 | -1.96 | 1.42 | -2.37 | 1.09 | -1.53 | 1.34 |
| **Ax2** | -1.14 | 0.61 | -2.02 | 1.48 | -1.99 | 1.00 | -0.79 | 1.33 |
| **Ax3** | -0.99 | 0.65 | -1.71 | 1.69 | -2.03 | 1.39 | -1.27 | 1.60 |
| **Ax4** | -0.56 | 2.02 | -1.61 | 1.71 | -2.26 | 1.12 | -1.58 | 1.77 |
| **ALNLRAC-RW-ZS** | | | | | | | | |
| **Ax1** | -2.33 | 1.98 | -3.16 | 2.13 | -2.63 | 2.01 | -1.72 | 1.62 |
| **Ax2** | -1.87 | 1.58 | -2.85 | 1.42 | -2.33 | 1.51 | -1.66 | 2.43 |
| **Ax3** | -1.16 | 1.19 | -1.73 | 2.13 | -2.26 | 1.82 | -1.88 | 2.21 |
| **Ax4** | -0.83 | 0.97 | -1.59 | 1.60 | -3.31 | 2.07 | -2.93 | 3.43 |

#### *6.5.2.2 Between-group analysis for differential intervention effectiveness of the FD Intervention on the ALNLRAC-NW-ZS, the ALNLRAC-IW-ZS, and the ALNLRAC-RW-ZS*

The use of difference scores was employed to further explore the differential intervention effectiveness for the different word reading measures, rather than using the permutational ANOVA. This was because there were significant group differences in all three measures at Ax1 (ALNLRAC-RW-ZS: $F(3, 16) = 2.69$, $p = 0.043$; ALNLRAC-NW-ZS: $F(3, 16) = 8.38$, $p = 0.000$;

and ALNLRAC-IW-ZS: $F(3, 16) = 6.42$, $p = 0.000$). Hence, it would be difficult to determine whether the potential differences in time, group, and interaction from the permutational ANOVA were due to the initial group differences or whether they reflect the effect of interventions. Difference score analyses allow for the comparison of the amount of change in performance between the groups regardless of their scores at Ax1. Hence, it was considered to be appropriate for use despite the initial group difference.

Between-group analyses of the difference scores of the ALNLRAC-NW-ZS, ALNLRAC-IW-ZS, and ALNLRAC-RW-ZS during Phase 1 of the FD-PP group and the two no intervention groups (i.e., the PP and CON groups) were conducted to investigate the effect of the FD intervention on word reading ability.

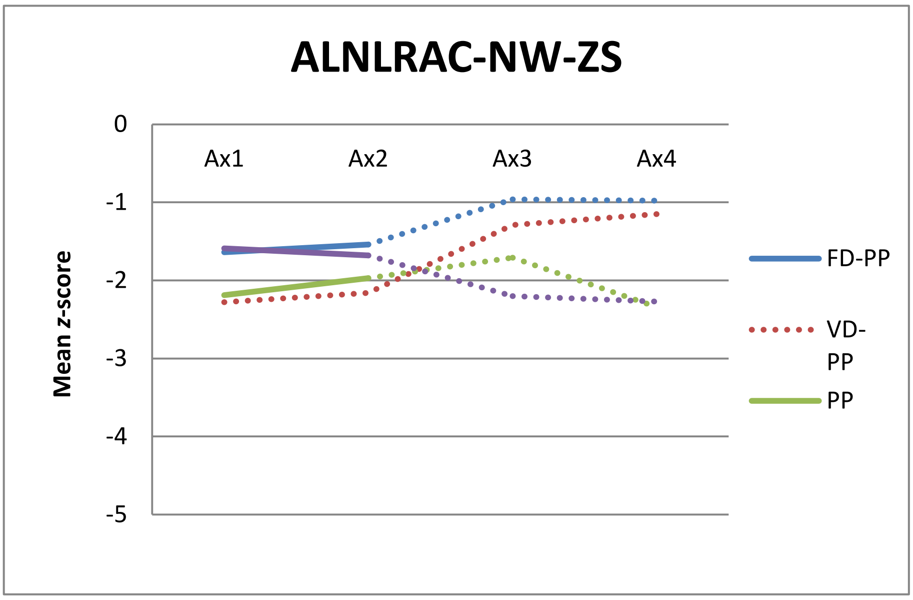


**Figure 6.17: Mean ALNLRAC-NW-ZS of the FD-PP group, PP group, and CON group across Ax1 and Ax2 (Phase 1)**

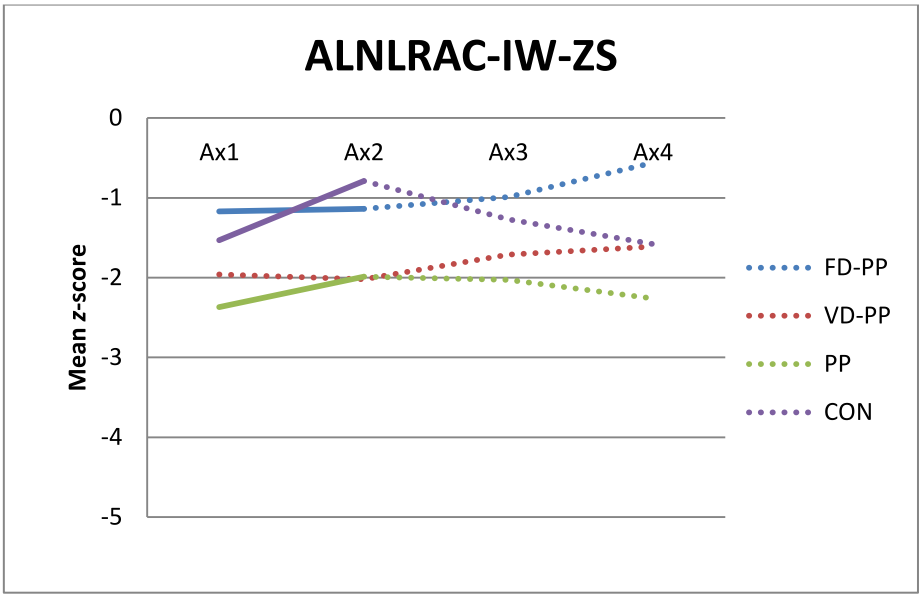


**Figure 6.18: Mean ALNLRAC-IW-ZS of the FD-PP group, PP group, and CON group across Ax1 and Ax2 (Phase 1)**

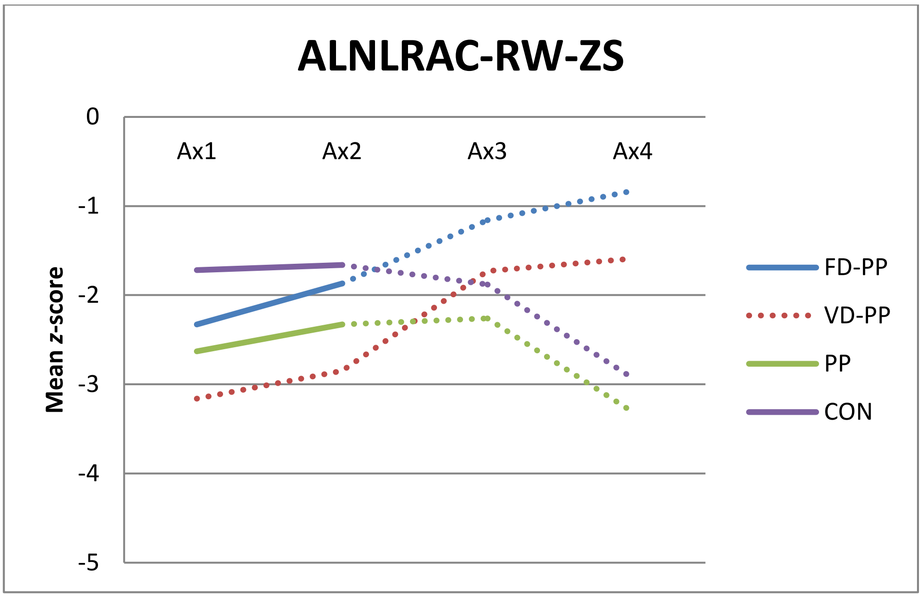


**Figure 6.19: Mean ALNLRAC-RW-ZS of the FD-PP group, PP group, and CON group across Ax1 and Ax2 (Phase 1)**

The means of the ALNLRAC-NW-ZS, ALNLRAC-IW-ZS, and ALNLRAC-RW-ZS across Ax1 and Ax2 of the FD-PP and the two groups that did not undergo intervention during Phase 1 (i.e., the PP, and CON groups) are highlighted in Figure 6.17, Figure 6.18 and Figure 6.19. The results of the difference score comparisons between Ax1 and Ax2 of the FD-PP group verses the PP and CON groups are presented in Table 6.8. The results show that the change in performance of the

FD-PP group across Ax1 and Ax2 did not differ significantly from those of the PP and the CON groups in all three word reading measures (*p*-value ranged between $p = 0.43$ and 0.999). The effect size data from these comparisons showed A statistics that were mostly small and non-significant. Therefore, the results show that the effect of FD intervention did not generalise to any of the word reading measures.

**Table 6.8: Results of the comparisons of the difference scores between Ax1 and Ax2 of the FD-PP group vs. the PP and the CON groups for ALNLRAC-RW-ZS, ALNLRAC-NW-ZS, and ALNLRAC-IW-ZS**

| | **FD-PP vs. PP** | | | **FD-PP vs. CON** | | |
|---|---|---|---|---|---|---|
| | *p* | A | 95% CI of A | *p* | A | 95% CI of A |
| **ALNLRAC-NW-SS** | 0.53 | 0.60 | 0.19 – 1.00 | 0.999 | 0.60 | 0.19 – 1.00 |
| **ALNLRAC-IW-SS** | 0.429 | 0.65 | 0.25 – 1.00 | 0.103 | 0.82 | 0.54 – 1.00 |
| **ALNLRAC-RW-SS** | 0.714 | 0.60 | 0.13 – 1.00 | 0.556 | 0.62 | 0.21 – 1.00 |

#### *6.5.2.3 Between-group analysis for differential intervention effectiveness of the PP Intervention on the ALNLRAC-NW-ZS, the ALNLRAC-IW-ZS, and the ALNLRAC-RW-ZS*

The between-group, difference score analyses of the ALNLRAC-NW-ZS, ALNLRAC-IW-ZS, and ALNLRAC-RW-ZS during Phase 2 (Ax2-Ax3) of the groups that underwent the PP intervention (i.e., the FD-PP, VD-PP, and PP groups) and the CON group were conducted to investigate the effect that the PP intervention had on the reading of the different types of words.

The means of the ALNLRAC-NW-ZS, ALNLRAC-IW-ZS, and ALNLRAC-RW-ZS of the FD-PP, VD-PP, PP, and CON groups across Phase 2 (i.e., Ax2 and Ax3) are highlighted in Figure 6.20, Figure 6.21 and Figure 6.22. Comparisons of the difference scores between Ax2 and Ax3 were conducted for the groups that undertook PP intervention (i.e., the FD-PP, VD-PP, and PP groups) versus the CON group. These results are presented in Table 6.9.

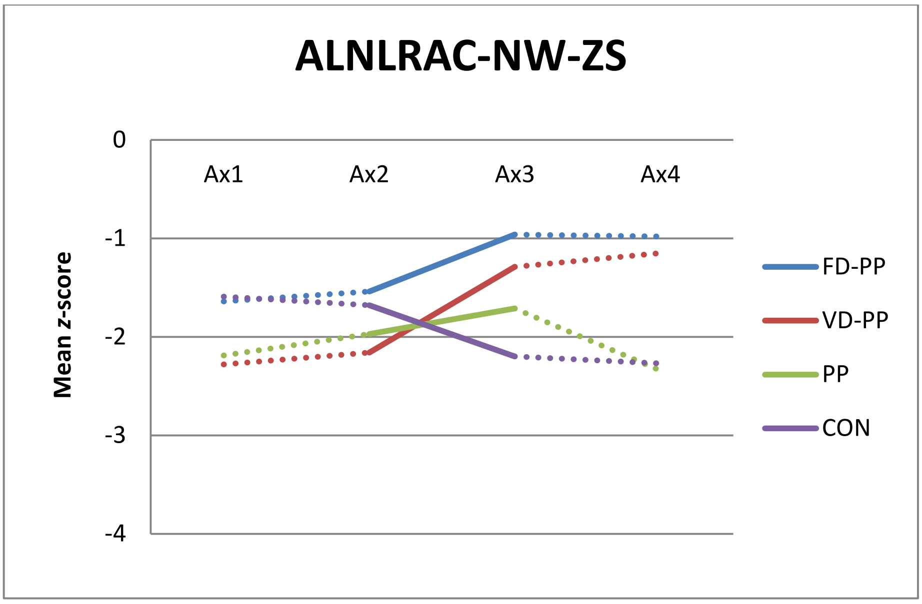


**Figure 6.20: Mean ALNLRAC-NW-ZS of the FD-PP group, VD-PP group, PP group, and CON group across Ax2 and Ax3 (Phase 2)**

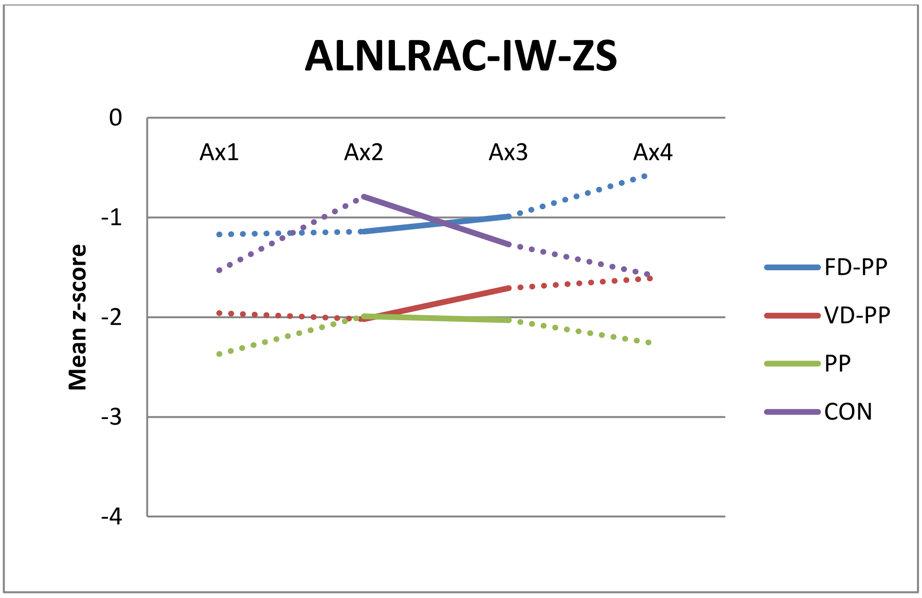


**Figure 6.21: Mean ALNLRAC-IW-ZS of the FD-PP group, VD-PP group, PP group, and CON group across Ax2 and Ax3 (Phase 2)**

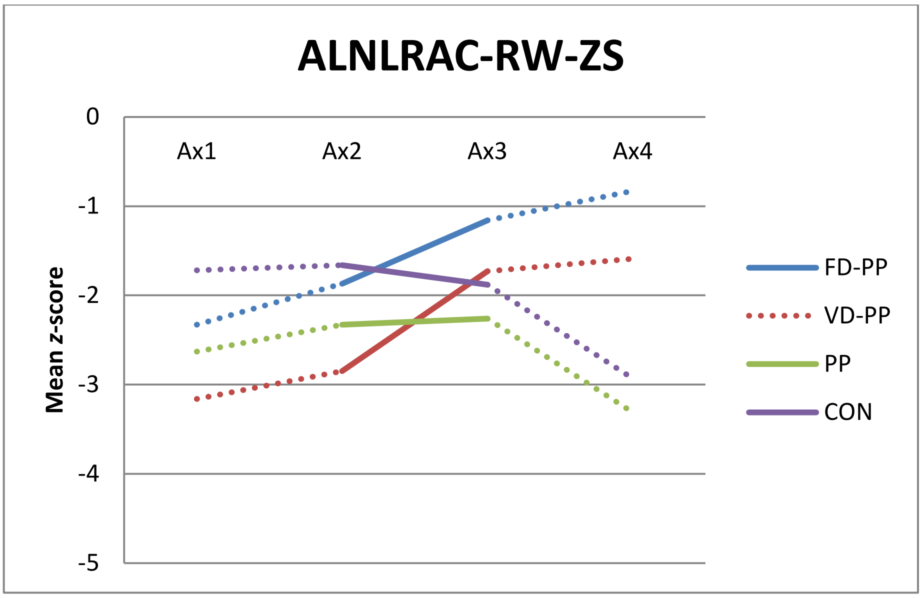


**Figure 6.22: Mean ALNLRAC-RW-ZS of the FD-PP group, VD-PP group, PP group, and CON group across Ax2 and Ax3 (Phase 2)**

The results show that the change in performance of the PP and CON groups across Phase 2 did not differ significantly for **each of the three word reading scores** (*p* value ranged from $p$ = 0.063 to $p$ = 0.651). However, the effect size data of the comparisons between the PP group versus the CON group showed a large and significant ES for **non-word reading** (ALNLRAC-NW-ZS: A = 0.90, 95% CI of A = 0.67-1.00). There were no significant ESs for **irregular word reading** and **regular word reading** in the comparisons between the PP group versus the CON group, i.e., the ES for ALNLRAC-IW-ZS was A = 0.70, 95% CI of A = 0.31-1.00, and ALNLRAC-RW-ZS was A = 0.65, 95% CI of A = 0.20-1.00.

The results of the difference score comparisons of the FD-PP and VD-PP groups, versus the CON group across Phase 2 showed the FD-PP and the VD-PP groups demonstrated significantly greater improvement than the CON group for **non-word** and **regular word reading** (ALNLRAC-NW-ZS: FD-PP vs. CON, $p$ = 0.016; VD-PP vs. CON, $p$ = 0.004 respectively, and ALNLRAC-RW-ZS: FD-PP vs. CON, $p$ = 0.047; VD-PP vs. CON, $p$ = 0.039 respectively). These differences were accompanied by large and significant ESs of A = 0.87 to 1.00, 95% CI of A = 0.65-1.00 (see Table 6.9).

However, no significant differences were identified in the difference score analyses of the FD-PP and VD-PP groups, versus the CON group for **irregular word reading** across Phase 2 (ALNLRAC-IW-ZS: FD-PP vs. CON, $p = 0.111$; VD-PP vs. CON group, $p = 0.100$). Nevertheless, the effect size data of these comparisons showed large and significant effect sizes (FD-PP vs. CON: A = 0.82, 95% CI of A = 0.63-1.00; and VD-PP vs. CON: A = 0.88, 95% CI of A = 0.55-1.00) (see Table 6.9).

Therefore, the results provide partial evidence for the generalisation of the PP intervention effect to non-word and regular word reading. The significant improvement demonstrated by two of the three groups that undertook PP intervention (i.e., the FD-PP and the VD-PP groups) was only observed after undertaking the PP intervention in Phase 2, and not after the FD or VD interventions in Phase 1. This shows that PP intervention was required in order to improve non-word and regular word reading. A large and significant effect size was observed when comparing the change in performance in non-word reading of the PP group versus the CON group which suggest that PP intervention was likely (i.e., with 95% certainty) to have an effect on non-word reading.

**Table 6.9: Results of the comparisons of the difference scores between Ax2 and Ax3 of the FD-PP, VD-PP, and PP groups vs. the CON group on ALNL-RAC-RW-ZS, ALNLRAC-NW-ZS, and ALNLRAC-IW-ZS**

| | **PP vs. CON** | | | **FD-PP vs. CON** | | | **VD-PP vs. CON** | | |
|---|---|---|---|---|---|---|---|---|---|
| | *p* | A | 95% CI of A | *p* | A | 95% CI of A | *p* | A | 95% CI of A |
| **ALNLRAC-NW-ZS** | 0.063 | 0.90 | 0.67-1.00 | 0.016 | 1.00 | 1.00-1.00 | 0.004 | 1.00 | 1.00-1.00 |
| **ALNLRAC-IW-ZS** | 0.381 | 0.70 | 0.31-1.00 | 0.111 | 0.88 | 0.63-1.00 | 0.100 | 0.82 | 0.55-1.00 |
| **ALNLRAC-RW-ZS** | 0.603 | 0.65 | 0.20-1.00 | 0.047 | 0.93 | 0.75-1.00 | 0.039 | 0.87 | 0.65-1.00 |

The results also suggest that PP intervention in isolation showed limited generalisation effect to irregular word reading. The change in performance of the PP group did not differ significantly from that of the CON group on irregular word reading following the PP intervention, nor was there any significant effect size. Large and significant effect sizes were observed in the comparisons between the FD-PP and VD-PP groups, versus the CON group for irregular word reading after Phase 2, which were absent in the comparisons of these groups after Phase 1, but these comparisons did not reach statistical significance.

### 6.5.3 Generalisation of the FD Intervention and the PP Intervention effects to receptive vocabulary and sentence comprehension (Research Question C.2b)

The generalisation effects of FD and PP interventions to receptive vocabulary and sentence comprehension were measured by using the standard score of the PPVT (PPVT-SS) and the standard score of the TROG (TROG-SS) respectively. The means of the PPVT-SS and the TROG-SS of the four groups across Ax1, Ax2, Ax3, and Ax4 are displayed in Figure 6.23 and Figure 6.24. Summary PPVT-SS and TROG-SS data are presented in Table 6.10.

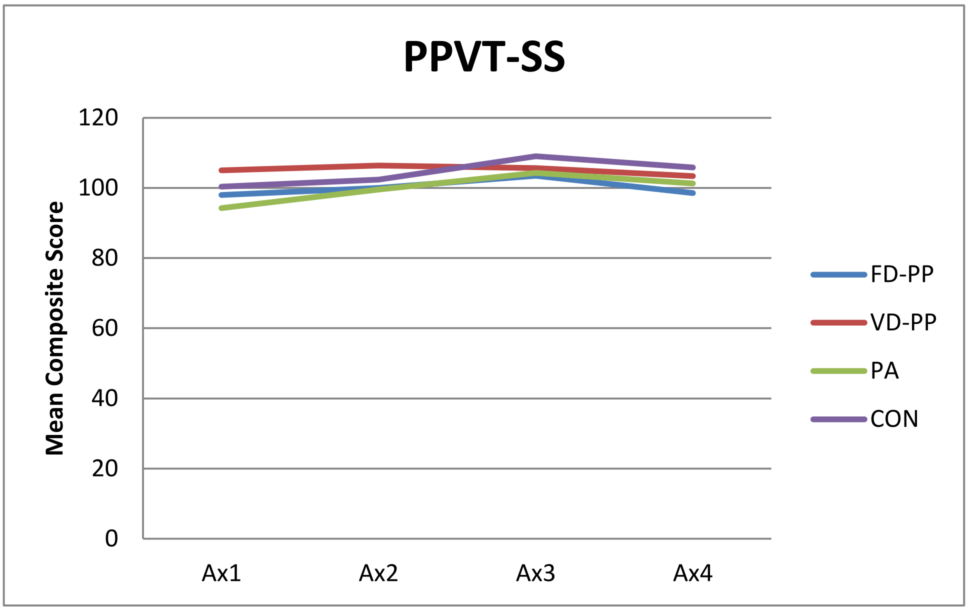


**Figure 6.23: Mean PPVT-SS of the FD-PP group, the VD-PP group, the PP group, and the CON group across Ax1, Ax2, Ax3, and Ax4**

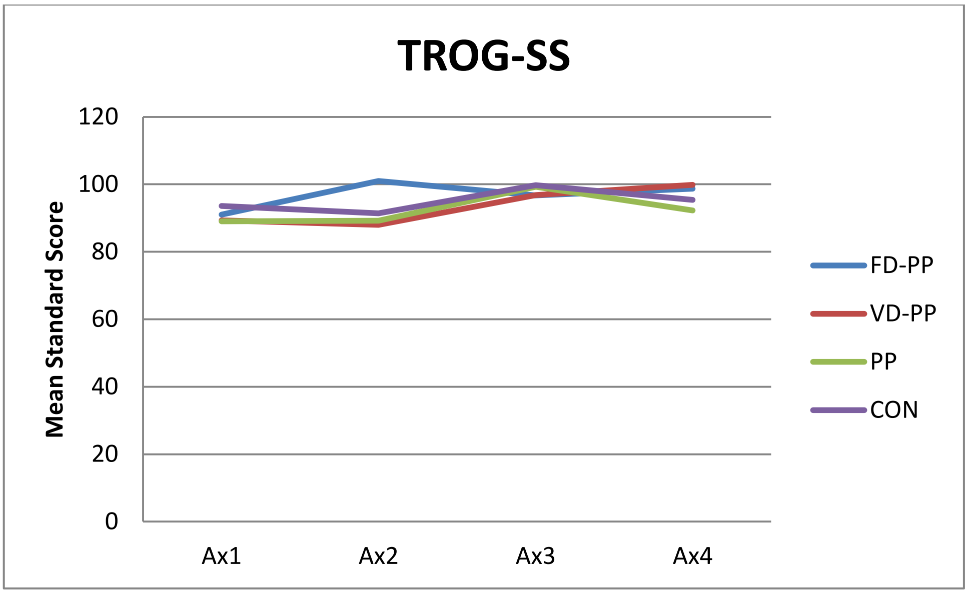


**Figure 6.24: Mean PPVT-SS and TROG-SS of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

**Table 6.10: Summary PPVT-SS and TROG-SS data of the FD-PP group, VD-PP group, PP group, and CON group across Ax1, Ax2, Ax3, and Ax4**

| | FD-PP | | VD-PP | | PP | | CON | |
|---|---|---|---|---|---|---|---|---|
| **PPVT-SS** | M | SD | M | SD | M | SD | M | SD |
| **Ax1** | 98.00 | 18.07 | 105.00 | 11.83 | 94.25 | 12.69 | 100.40 | 7.89 |
| **Ax2** | 100.00 | 6.16 | 106.33 | 27.54 | 99.50 | 12.01 | 102.40 | 4.45 |
| **Ax3** | 103.50 | 11.03 | 105.67 | 15.79 | 104.25 | 10.18 | 109.00 | 3.08 |
| **Ax4** | 98.50 | 14.06 | 103.33 | 13.46 | 101.25 | 11.03 | 105.80 | 5.36 |
| **TROG-SS** | | | | | | | | |
| **Ax1** | 91.00 | 12.61 | 89.33 | 8.62 | 89.00 | 8.04 | 93.60 | 16.56 |
| **Ax2** | 101.00 | 7.31 | 88.00 | 17.27 | 89.25 | 6.70 | 91.40 | 11.01 |
| **Ax3** | 96.75 | 14.52 | 96.83 | 8.30 | 99.25 | 5.91 | 99.80 | 15.12 |
| **Ax4** | 98.75 | 3.40 | 99.83 | 10.96 | 92.25 | 13.60 | 95.40 | 10.04 |

#### *6.5.3.1 The PPVT-SS and TROG-SS of the entire sample over the duration of the study*

Despite the fact that the mean scores showed some improvement on the TROG during Phase 2 (Ax2-Ax3) in the PP group (10 points) and the VD-PP group (nearly 9 points), the results of the permutational ANOVA with repeated measures showed that there were no significant main effects for time (PPVT-SS: F(3, 64) = 0.87, $p$ = 0.460; TROG-SS: F(3, 64) = 2.13, $p$ = 0.102), group

(PPVT-SS: F(3, 64) = 1.10, $p$ = 0.357; TROG-SS: F(3, 64) = 0.84, $p$ = 0.477) and interaction (PPVT-SS: F(9, 64) = 0.13, $p$ = 0.998; TROG-SS: F(9, 64) = 0.50, $p$ = 0.877) on both language measures. Therefore, the results showed that neither FD intervention nor PP intervention had any effect in improving receptive vocabulary and sentence comprehension (Research Question C.2).

## 6.6 Effect of Prior FD Intervention on the outcomes of PP Intervention

The potential effect that prior FD intervention might have on the PP intervention outcomes was investigated by comparing the outcomes of the FD-PP and the PP groups for the following measures: the PP Intervention Literacy Score (i.e., the PP-I-LS), the Phonological Awareness Composite Score of the CTOPP (i.e., the CTOPP-PA-CS), and the non-word reading, regular word reading and irregular word reading *z*-scores (i.e., the ALNLRAC-NW-ZS, ALNLRAC-RW-ZS, and ALNLRAC-IW-ZS respectively). These measures were chosen because they reflect phonological processing and reading abilities, and hence, were deemed to be most relevant to the PP intervention.

Difference score analysis was again used to determine whether prior FD intervention had any enhancing effects on PP intervention outcomes. The difference between Ax2 and Ax3 scores of the FD-PP group was compared to those of the PP group for the different measures to determine whether the FD-PP group had greater improvement than the PP group.

### 6.6.1 The effect of prior FD Intervention on the PP-I-LS (Research Question D.1a)

The means of the PP-I-LS of the FD-PP and PP groups across Ax2 and Ax3 are highlighted in Figure 6.25. Different score comparisons of the FD-PP and PP groups' PP-I-LS between Ax2 and Ax3 showed that the two groups did not differ significantly ($p$ = 0.114). The A statistic showed a large and significant effect size (A = 0.88, 95% CI of A = 0.59 to 1.00, but the 95% CI of A showed a wide interval and suggest that there is the possibility that A could be as small as A= 0.59). Thus, the results did not support the notion that improved FD had enhanced the effect of the PP intervention for the PP-I-LS (Research Question D.1a).

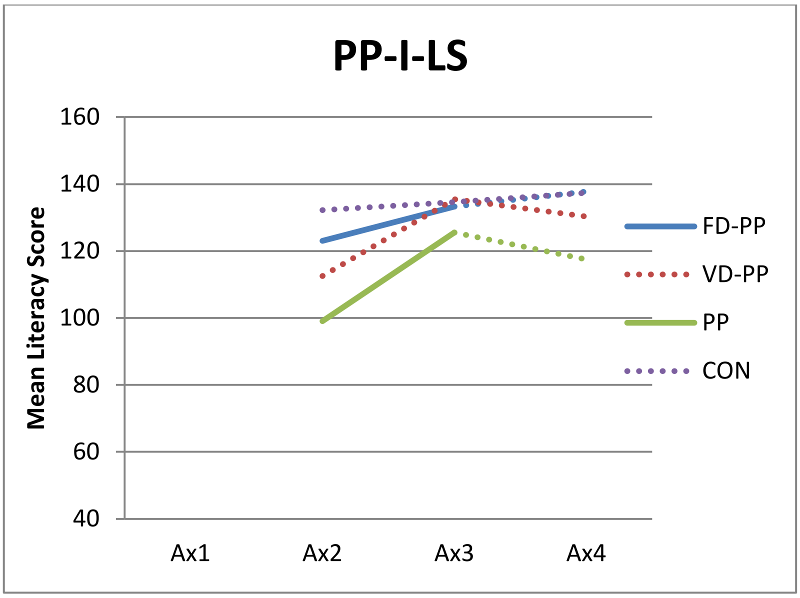


**Figure 6.25: Mean PP-I-LS of the FD-PP and PP groups across Ax2 and Ax3**

### 6.6.2 Effect of prior FD Intervention on the CTOPP-PA-CS (Research Question D.1b)

The means of the CTOPP-PA-CS of the FD-PP and PP groups across Ax2 and Ax3 are highlighted in Figure 6.26. Difference score comparisons of the FD-PP and PP groups' CTOPP-PA-CS between Ax2 and Ax4 showed that the two groups did not differ significantly ($p$ = 0.063). The A statistic also showed a minimal and non-significant effect size (A = 0.56, 95% CI of A = 0.12 – 1.00).

As mentioned in Section 6.5.1.2.1, the pair-wise comparisons showed that the significant main effect for groups on the CTOPP-PA-CS was due to significant differences in the performance of the FD-PP group and the other three intervention groups across the entire study period (the FD-PP group vs. the VD-PP group: $t(4)$ = 2.41, $p$ = 0.023; the FD-PP group vs. the PP group: $t(4)$ = 2.44, $p$ = 0.023; and the FD-PP group vs. the CON group, $t(4)$ = 3.00, $p$ = 0.005). This was in the absence of any initial significant differences amongst the groups at Ax1 ($F(3, 16)$ = 0.85, $p$ = 0.500); also there were no significant differences between the performance of the other three groups across the study period (the VD-PP group vs. the PP group, $t(8)$ = 1.25, $p$ = 0.228; the VD-PP group vs. the CON group: $t(9)$ = 1.65, $p$ = 0.112; the PP group vs. the CON group, $t(7)$ = 0.40, $p$ = 0.706).

However, different scores analysis between the changes in the scores of the intervention groups and the CON group failed to reach statistical significance (see Section 6.5.1.2.2). Therefore, the results provide only partial evidence to suggest that the combined effects of the FD intervention and the PP intervention produced greater improvement in phonological awareness than the independent effect of the PP intervention.

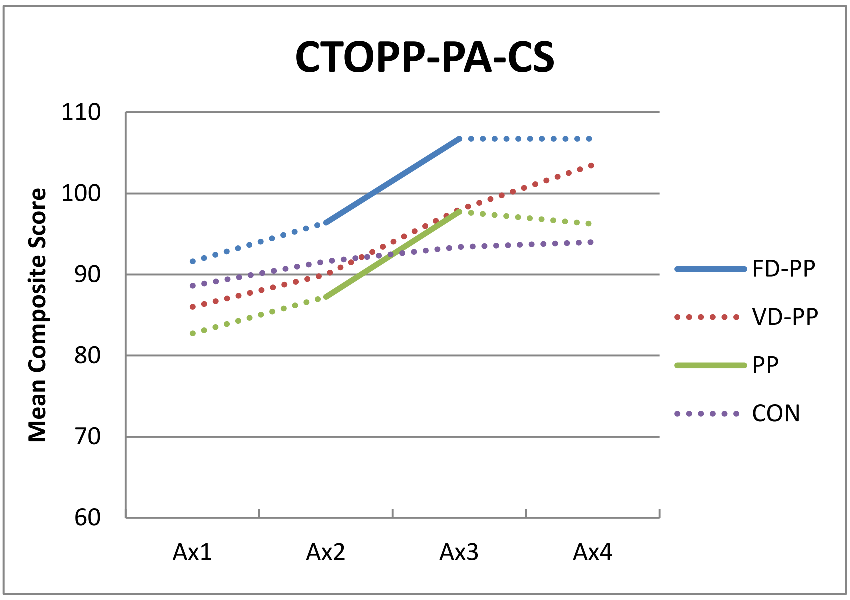


**Figure 6.26: Mean CTOPP-PA-CS of the FD-PP and PP groups across Ax2 and Ax3**

### 6.6.3 Effect of prior FD intervention on the ALNLRAC-NW-ZS, ALNLRAC-RW-ZS, and ALNLRAC-IW-ZS (Research Question D.1c)

The means of the ALNLRAC-NW-ZS, ALNLRAC-RW-ZS, and ALNLRAC-IW-ZS of the FD-PP and PP groups across Ax2 and Ax3 are highlighted in Figure 6.27, Figure 6.28, and Figure 6.29. Difference score analysis of the **non-word reading** outcomes of the FD-PP group versus the PP group showed that the FD-PP group demonstrated a significantly greater improvement than the PP group with regards to non-word reading (ALNLRAC-NW-ZS: $p$ = 0.029, A = 1.00, 95% CI = 1.00 – 1.00). The A statistic showed the largest possible effect, with the 95% CI of A supporting that A is likely to be a value of 1.00.

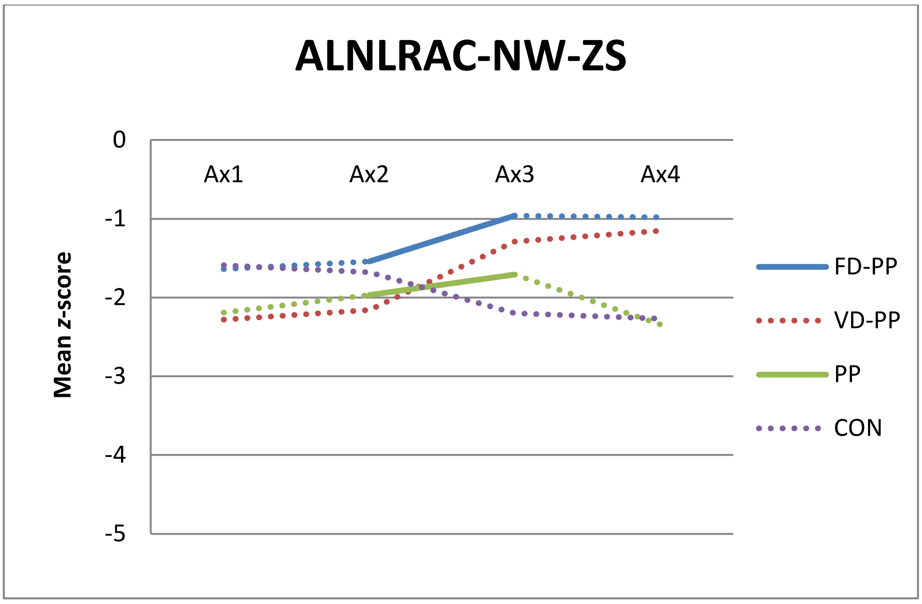


**Figure 6.27: Mean ALNLRAC-NW-ZS of the FD-PP and PP groups across Ax2 and Ax3 (Phase 2)**

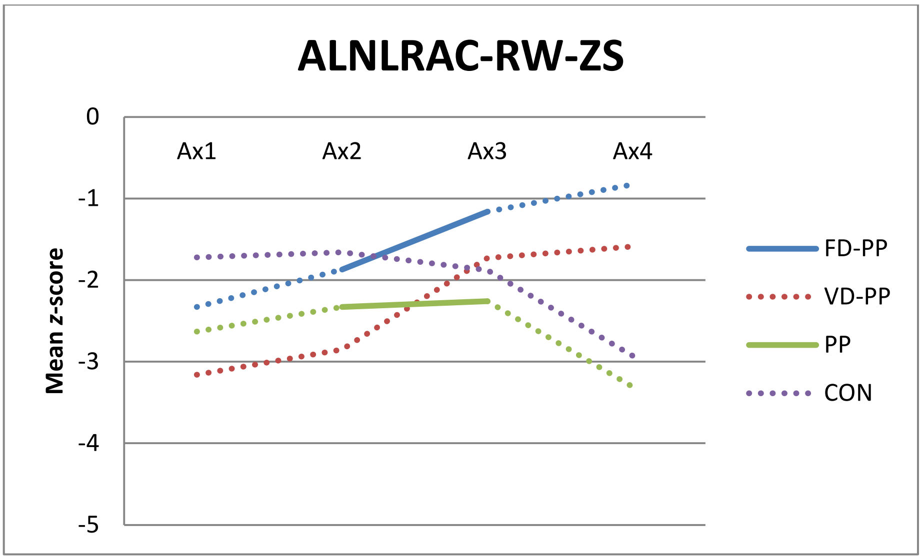


**Figure 6.28: Mean ALNLRAC-RW-ZS of the FD-PP and PP groups across Ax2 and Ax3 (Phase 2)**

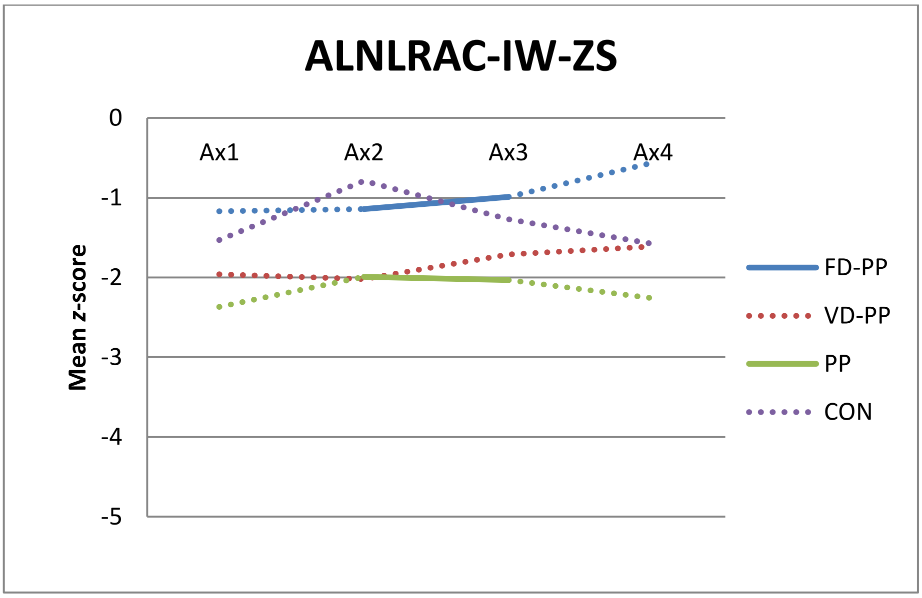


**Figure 6.29: Mean ALNLRAC-IW-ZS of the FD-PP and PP groups across Ax2 and Ax3 (Phase 2)**

However, the two groups did not differ significantly for **regular word reading** (ALNLRAC-RW-ZS: $p$ = 0.257, A = 0.69, 95% CI = 0.25 - 1.00). Nevertheless, as shown in Section 6.5.2.3, a significantly greater improvement was observed when comparing the difference scores of the FD-PP and the CON groups for this measure, ($p$ = 0.047, A = 0.93, 95% CI of A = 0.75-1.00), while no significant differences were observed between the PP group and the CON group ($p$ = 0.603, A = 0.65, 95% CI of A = 0.20 - 1.00). Therefore, this provides evidence that the FD-PP group achieved greater improvement than the PP group in regular word reading.

The difference score analysis for **irregular word reading** between the FD-PP and the PP groups across Ax2 and Ax3 shows that there was no significant difference between the change in performance of the two groups ($p$ = 0.400). However, the effect size data show a large and significant effect size (A = 0.88, 95% CI or A = 0.59 - 1.00).

Hence, these results showed that the FD-PP group had significantly greater improvement than the PP group for the reading of non-words and regular words. However, the FD-PP and PP groups did not differ significantly in their change in performance for irregular word reading, but a large and significant effect size was observed. Further analyses were conducted with respect to the VD-PP and the PP groups.

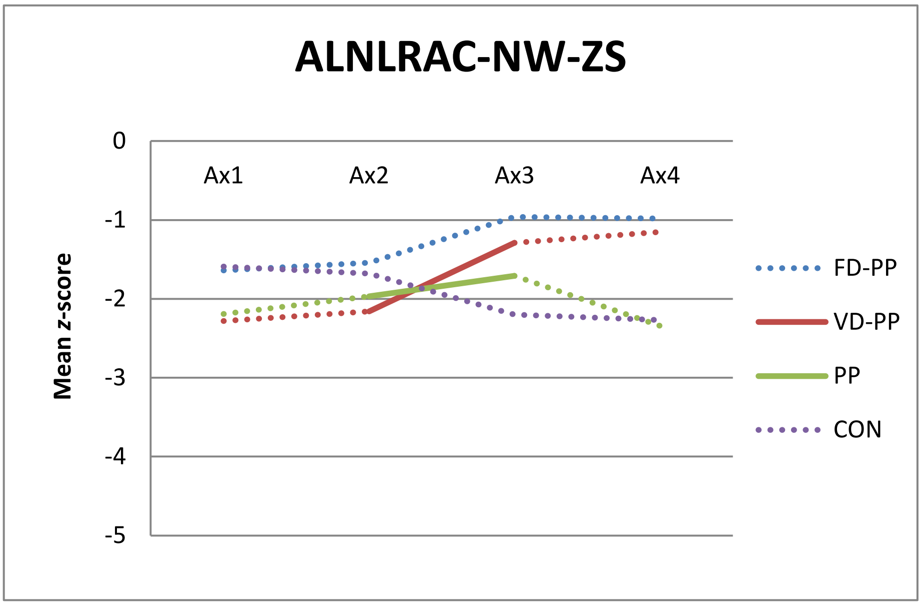


**Figure 6.30: Mean ALNLRAC-NW-ZS of the VD-PP and PP groups across Ax2 and Ax3 (Phase 2)**

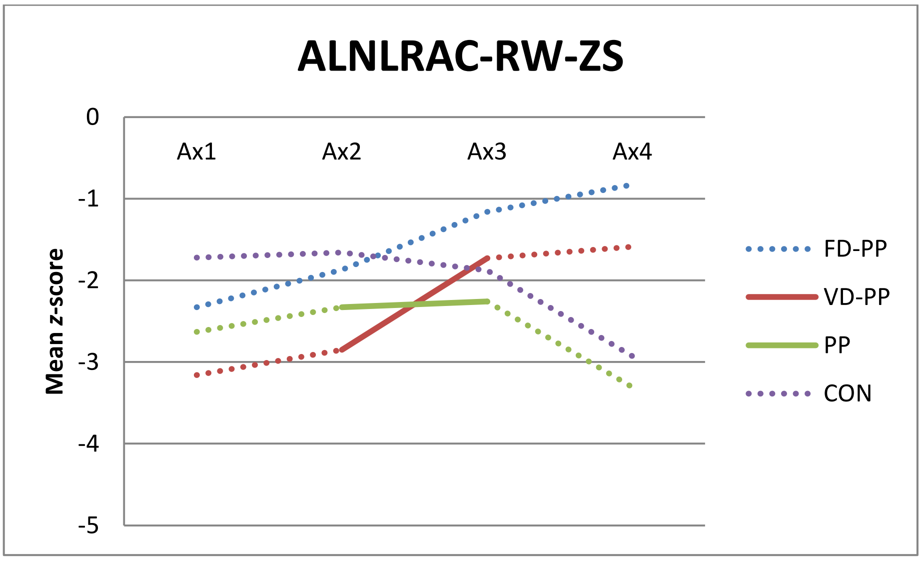


**Figure 6.31: Mean ALNLRAC-RW-ZS of the VD-PP and PP groups across Ax2 and Ax3 (Phase 2)**

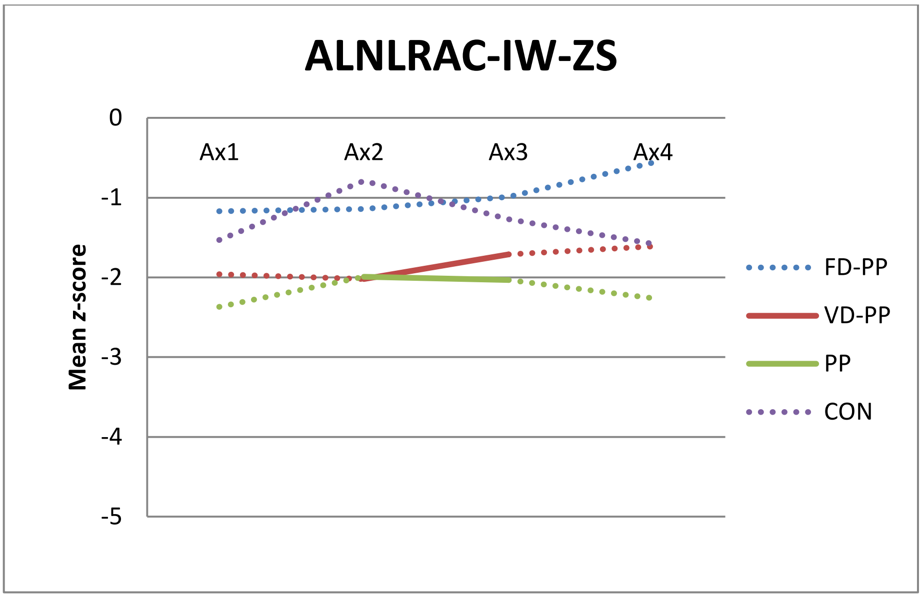


**Figure 6.32: Mean ALNLRAC-IW-ZS of the VD-PP and PP groups across Ax2 and Ax3 (Phase 2)**

The means of the ALNLRAC-NW-ZS, ALNLRAC-RW-ZS, and ALNLRAC-IW-ZS of the VD-PP and PP groups across Ax2 and Ax3 are highlighted in Figure 6.30, Figure 6.31, and Figure 6.32. The results of the difference score analysis showed that the VD-PP group also showed significantly greater improvement than the PP group on **non-word reading** across Phase 2 (ALNLRAC-NW-SS: $p$ = 0.010). The A statistic showed a large and significant effect size (A = 0.96, 95% CI = 0.87 – 1.00).

Nevertheless, the two groups did not differ significantly with regard to **regular word reading** (ALNLRAC-RW-SS: $p$ = 0.124, A = 0.79, 95% CI = 0.48 – 1.00). However, the VD-PP group achieved significantly greater improvement than the CON group on this measure ($p$ = 0.039, A = 1.00, 95% CI = 1.00 – 1.00), whereas there were no significant differences between the PP group and the CON group (see Section 6.5.2.3). Therefore, the results suggest that the VD-PP group achieved better regular word reading outcome than the PP group.

The difference score analysis of the VD-PP and the PP groups across Ax2 and Ax3 shows that the two groups did not differ significantly on **irregular word reading** following PP intervention ($p$ = 0.460). Again, there was a large and significant effect size (A = 0.88, 95% CI of A = 0.65-1.00).

Additional difference score analyses were conducted to determine if the FD-PP group achieved significant greater improvement than the VD-PP group for non-word and regular word reading, or vice versa. The results show that there were no significant differences between the change in performance of the FD-PP and VD-PP groups for non-word reading (ALNLRAC-NW-ZS: $p = 0.541$, A = 0.71, 95% CI of A = 0.23-1.00) and regular word reading (ALNLRAC-RW-ZS: $p = 0.761$, A = 0.56, 95% CI of A = 0.15-0.98). Comparisons on irregular word reading were not conducted because neither the FD-PP group nor the VD-PP group demonstrated significantly greater performance than the PP group across Ax2 and Ax3.

In summary, the results suggest that prior FD intervention did not enhance the PP intervention outcome for the PP-I-LS. However, there was partial support that it enhanced the PP intervention outcome for phonological awareness. This was specific to the FD-PP group and was not observed in the VD-PP group. The results also demonstrate that both prior FD and VD interventions enhanced the generalisation effect of PP intervention to non-word and regular word reading, but not for irregular word reading. The improvement in non-word and regular word reading achieved by the FD-PP and VD-PP groups was greater than the PP group to a similar extent.

## 6.7 Discussion

STUDY 2 addressed the question of whether prior FD intervention would lead to an enhanced outcome after PP intervention. In order to investigate this, the independent effects of the FD and PP interventions needed to be determined. Hence, the predictions that both FD and PP interventions would show significant intervention-specific improvements, as well as generalisation effects, were tested. Subsequently, the prediction that prior FD intervention would enhance the effects of the PP intervention was investigated.

This discussion is structured as follows:

1) Discussion of the intervention-specific effect of FD and PP interventions, and their maintenance effect.

2) Discussion of the generalisation effect of FD and PP interventions. This included the generalisation of the intervention effect to: a) a task that is similar to the intervention task (i.e., within-task generalisation); b) the reading of different types of words; and c) receptive language.
3) Discussion of the effects that prior FD intervention had on the outcomes of the PP intervention.

The results and findings will be summarised and discussed under the respective headings.

### 6.7.1 Intervention-specific effect of FD and PP interventions, and their maintenance effects

#### *6.7.1.1 Intervention-specific effect of the FD intervention*

The FD intervention showed a significant intervention-specific effect. The FD-PP group showed significantly greater improvement in the mean FD SoundsPod Threshold Score compared to the two groups that did not receive any intervention during Phase 1 (i.e., the PP and CON groups), and the group that received the VD intervention (i.e., the VD-PP group).

These findings with respect to children with APD are consistent with the findings with respect to children with SLI and SRD in a growing body of literature. Previous studies have addressed the effect of FD intervention or training in children with SLI and SRD (McArthur et al., 2008), and children recruited from the general population (Halliday et al., 2008; Halliday et al., 2012; Millward et al., 2011; Moore et al., 2008). These studies have demonstrated that FD ability can be improved by FD training. For example, McArthur et al. (2008) investigated the effect of FD intervention in a group of children with SRD and SLI. Children with comorbid FD difficulty showed significant improvement in FD following FD intervention. The findings of the present study add to this growing body of research demonstrating that the effectiveness of FD intervention extends to children with APD.

At the same time, the current findings also support the use of bottom-up intervention approaches in conjunction to top-down approaches in the management of APD. Bottom-up approaches focus on the training of the specific AP abilities that are found to underlie the child's APD. They stem from a large body of animal research and early studies in the adult population (see Chermak & Musiek, 2007; Chermak & Musiek, 1997 for reviews), demonstrating that the central auditory nervous system is plastic well into adulthood, and that cortical reorganisation (which has been shown to correlate with behavioural outcomes) can be influenced by auditory stimulation.

In recent years, the effectiveness of the use of bottom-up approaches in children with APD has been explored in a number of studies (Cameron & Dillon, 2011; English et al., 2003; Moncrieff & Wertz, 2008). All these studies showed significant pre-post task specific improvement. However, speech stimuli rather than non-speech stimuli were used as was the case in the present study. For instance, Cameron and Dillon (2011) investigated the training of binaural processing using a speech identification task. English et al. (2003) and Moncrieff and Wertz (2008) explored the effectiveness of dichotic training with speech repetition tasks. Hence, it is difficult to determine whether the outcomes of these interventions were due to improved AP, or whether they were the result of repeated exposure to the speech stimuli used in the interventions, which might have had some effect in strengthening speech and language processing.

The present study explored the training of one AP ability, namely FD, in a non-speech task (i.e., the FD intervention). Pure tones of different frequencies were presented to the child during the intervention. Because speech stimuli were not used, it was possible to train the AP ability separate from speech and language processing mechanism. Therefore, the observed effect of the FD intervention in the present study reflects improvement that is independent of speech and language processing. This was supported by the absence of improvements of the FD-PP group on the language measures (i.e., the PPVT-SS and the TROG-SS) following FD intervention (see Section 6.5.3). Additionally, the present study has incorporated a no-intervention control group. The group who undertook the FD intervention demonstrated significantly greater improvement in FD compared with the PP and CON groups (who did not received any intervention during Phase 1), as well as the group who received the VD intervention. This shows that the intervention-specific effect of the FD intervention could not be explained by other factors or potential experimental confounds, such as maturation, the Hawthorne effect, and/or the test-retest effect.

Moreover, the results suggest that the improvement observed in the FD-PP group was specific to the FD intervention and not related to other factors, such as the frequency or duration of training exposure. The significant improvement in FD was only seen in the FD-PP group and not in the VD-PP group who underwent the VD intervention. The VD intervention was a program that was identical to the FD intervention except that the discrimination training was in the visual modality. If the improvement in FD was a result of factors related to training exposure rather than being specific to the FD intervention, then the VD-PP group should also have demonstrated improved FD. In fact, the VD-PP group had longer exposure to the VD intervention than the FD-PP group to the FD intervention (see Section 6.2 for more details regarding this matter), which might have led to greater improvement due to longer training exposure. Hence, the present results suggest that the FD intervention resulted in significant intervention-specific effects that were specific to the FD intervention and unrelated to the duration of exposure.

Finally, the results also showed that FD ability can be improved with minimal practice. The SoundsPod Threshold Score (i.e., the FD-SOUND-TS) of the groups that did not undertake the FD intervention also showed a reduction in the threshold score over the course of the study (see Section 6.3.1). The threshold score showed a significant time effect across all groups, but there was no significant group effect or interaction. This might suggest that there was substantial practice effect inherent in the FD task. Thus, improvement in the FD task might happened rapidly with minimal, repeated task exposure, since the groups that did not undertake the FD intervention were only exposed to the FD task four times during repeated assessment over the course of the study. A few previous studies have also reported that FD performance can improve after minimal task exposure (Halliday et al., 2008; Moore et al., 2008). Halliday et al. (2008) found that it was possible to improve FD ability in children during one single training session. They observed that FD learning happened rapidly and was typically confined to the earlier part of the session (< the first 225 trials).

#### *6.7.1.2 Maintenance of the FD intervention effects*

The results showed that the effect of the FD intervention was maintained throughout the study period at Ax2, Ax3 and Ax4 as demonstrated by the lack of significant changes in FD performance of the FD-PP group from Ax2 through to the maintenance phase (Ax4). Maintenance effects of FD intervention have been largely unexplored in previous studies involving children with APD, SRD or SLI. Only one study had demonstrated that FD performance remained stable over a period of time in children with SLI. McArthur and Bishop (2004) investigated the reliability of a FD task in a group of 11 participants with SLI and 13 controls. The participants were tested and retested over an 18 month period. The authors found a moderate correlation ($r = 0.61$, $p = 0.002$) between the FD threshold scores of the first and the second assessment. They concluded that the FD threshold scores remained consistent over the 18 month period in the absence of any intervention. The results of the present study build on this finding and show that significant improvement in FD resulted from FD intervention could be maintained across a period of no-intervention, in this case, a 12 week period in children with APD.

#### *6.7.1.3 Intervention-specific effects of the PP intervention*

The results of the present study showed that PP intervention demonstrated a significant intervention-specific effect. All groups who undertook the PP intervention (the PP, FD-PP, and VD-PP groups) demonstrated significantly greater improvement in terms of the intervention-specific measure of the PP intervention (i.e., the PP-I-LS) after the PP intervention compared to the CON group. There were no significant differences across the improvements gained by the three intervention groups.

The PP Intervention-Specific Literacy Score was an accuracy score based on reading and writing of the stimulus words used during the PP intervention. The finding of the present study is in agreement with the findings of other studies showing that computer-based interventions addressing PP are effective in improving word reading and spelling abilities (Ecalle, Magnan, Bouchafa, & Gombert, 2009; Lynch, Fawcett, & Nicholson, 2000; Magnan & Ecalle, 2006; Nicholson, Fawcett, & Nicholson, 2000; Tijms, 2011). However, the direct intervention-specific effects of these interventions were not measured because most studies had examined intervention effectiveness based on reading and spelling assessments with target words that were not included in the intervention programs.

#### *6.7.1.4 Maintenance of the intervention-specific effect of PP intervention*

The PP intervention-specific effect was also maintained over the course of the study from Ax3 to Ax4. Within-group comparison of the PP group's PP Intervention-Specific Literacy Score showed that there were no significant changes in performance during the Maintenance Phase (between Ax3 and Ax4). This result is consistent with a large body of research that have also demonstrated the long-term effects of PP interventions, albeit in populations other than individuals with APD (e.g. Coyne, Kame'enui, Simmons, & Harn, 2004; Fuchs et al., 2001; Hatcher, Hulme, & Ellis, 1994; Torgesen et al., 2001; Vellutino et al., 1996). For instance, Vellutino et al. (1996) showed that the reading and spelling improvements observed in a group of at-risk first-grade students who underwent an intervention that explicitly targeted letter-sound decoding was maintained after one year. Hatcher et al. (1994) compared the reading outcome of a group of 7-year-old students with reading difficulties who undertook a decoding intervention and a control group. They found that the intervention group made significantly greater improvements in non-word reading than the control group, and these gains were maintained at the 9-month follow-up. Ehri et al. (2001) conducted a systematic review and meta-analysis of the effect of reading interventions that targeted letter-sound correspondences in children with reading difficulties. They observed that these interventions exert a moderate, significant effect on word reading, spelling, and reading comprehension. These effects were maintained at follow-ups of up to one year. In summary, the results of the present study showed that both the FD and PP interventions resulted in significant intervention-specific improvements in children with APD, which were maintained over the course of the study.

### 6.7.2 Generalisation effects of FD and PP interventions

#### *6.7.2.1 Generalisation of the FD intervention effect to a similar FD task (within-task generalisation)*

Despite significant intervention-specific improvement, the effect of FD intervention did not generalise to a similar FD task. There was no significant improvement in the FD-PP group's performance on the Dinosaur Task after the FD intervention. Additionally, there were no significant differences between the change in performance of the FD-PP group and the other three groups on the Dinosaur Task after Phase 1 (at Ax2).

One explanation for the lack of generalisation might be the differences between the two tasks. For instance, the visual interface of the two tasks is different. Therefore, it could have been that some of the participants found one FD task more motivating than the other, and this may have caused some variation in engagement and task performance. Another factor could be that the two tasks employ different algorithms for response adjustment and different criteria for threshold estimations. The frequency difference between the standard tone and the target tone in both tasks is adjusted according to the child's level of performance accuracy. For the SoundsPod, this is adjusted using the PEST procedure (Taylor & Creelman, 1967), but for the Dinosaur Task, a variation of the original PEST is used, which is referred to as the 'More Virulent PEST' (Findlay, 1978). Findlay made modification to the original algorithms in an attempt to increase the efficiency and accuracy of threshold estimation. Computer simulations were used to compare the threshold estimates of his version of the PEST and the original one. The difference between the means of the threshold estimates obtained from 500 simulation trials of the two versions of PEST was compared, and the results showed that there was no statistical significance between them (Findlay, 1978). Based on these results, it seemed unlikely that the lack of within-task generalisation of the FD intervention effect was due to the difference in the algorithm of the two FD tasks.

Another factor that might have contributed to the lack of within-task generalisation of the FD intervention was the difference in trial presentation of the two tasks. The trials are presented continuously in the SoundsPod, where each trial is presented immediately after the feedback for a previous trial is given. However, in the Dinosaur Task, the child is required to click on a box on the screen to initiate each trial. This is to help the child to attend to the task before the presentation of the stimuli in an attempt to reduce the number of incorrect responses caused by a lack of readiness. Therefore, the significant improvement of the FD-PP group's performance on the SoundsPod might have been the result of improved 'readiness-to-respond' rather than an improvement in FD *per se*. In other words, it could be that after the FD intervention, the children in the FD-PP group improved in their ability to respond to continuously presented stimulus trials rather than showing better FD. Therefore, the improvement did not generalise to the Dinosaur Task because the design of the Dinosaur Task had eliminated the need to process continuously presented stimuli.

Further research is required to determine what constitutes this ability to respond to continuously presented trials, and in particular whether attention might be a contributing factor. A number of previous studies have documented the effects of attention on FD ability (Moore et al., 2010; Moore et al., 2008; Sutcliffe et al., 2006). For instance, Moore et al. (2010) attested that poor performance in FD tasks could be attributed to inattention in the majority of children with FD difficulty rather than the poor processing of acoustic signals. In their supplementary material, Moore et al. (2010) reported that visual phasic attention/alertness was found to be significantly related to FD thresholds but not auditory phasic attention/alertness. Visual phasic attention is 'the ability to increase response readiness for a short period of time subsequent to external cues or stimuli’ (Sturm & Willmes, 2001, pp. S76) (see Section 4.2.3 for more details). Moore et al. found that children with poor visual phasic attention/alertness also performed poorly on FD task that involved the continual presentation of stimuli. It is unclear how visual phasic alertness contributes to performance on FD tasks, but according to Moore et al., it could be that good performance on FD tasks that involve the continual presentaiton of stimuli requires good visual phasic attention. Therefore, the improvement in FD following FD intervention observed in the present study might be a result of improved visual phasic attention. The lack of within-task generalisation of the FD intervention to the Dinosaur Task might be because the Dinosaur task relies less on visual phasic attention due to its ‘trial initiation’ feature.

Further research is required to determine whether FD training could result in genuine improvement in FD which would generalise to other FD tasks. Studies could consider training FD using a task that does not involve the continual presentation of stimuli and then measuring within-task generalisation through another task that also does not involve the continual presentation of stimuli. This might reduce the contribution that visual phasic atttenion have on FD performance and intervention outcome. Additionally, to further explore the contribution that visual phasic attention has on FD, future studies could consider comparing children’s performance on two different FD tasks that are identical in all aspects with the exception of the trial initiation feature. They could incorporate measures of visual processing and attention to explore whether performance on either of the FD tasks correlate significantly to these cognitive processes. Additionally, measures of visual phasic attention, such as the IHR Cued Attention Test (Riley, Ferguson, Ratib, & Moore, 2009) used in Moore et al. 2010, could be included in future studies that compare the pre-post intervention changes on FD tasks. Changes in visual phasic attention pre-post intervention could be monitored to determine whether such changes were associated with changes in FD performance.

#### *6.7.2.2 Generalisation of the FD intervention-effect to word reading and language ability*

Improved FD ability did not lead to improvement in reading or receptive language. Despite significant improvement in FD, there were no significant group differences between the FD-PP group and the three other groups on any of the word reading measures (i.e., the ALNLRAC-RW-ZS, the ALNLRAC-IW-ZS, and the ALNLRAC-NW-ZS), or the language measures (i.e., the PPVT-SS, and the TROG-SS) following FD intervention (at Ax2).

A lack of generalisation to word reading and language has also been reported in a couple of previous studies (Halliday et al., 2012; McArthur et al., 2008). For instance, McArthur et al. (2008) reported significant task-specific FD improvement pre-post FD intervention. However, changes in spoken language, word reading, and spelling scores of the intervention group were no greater than those of the control group (see Section 2.4.4.2). The authors concluded that the effect of the FD intervention did not generalise to language, reading or spelling abilities. In a larger study, Halliday et al. (2012) again reported a lack of generalisation of the FD intervention effect to phonological awareness and word reading (see Section 2.4.4.2). Similar to the present study, Halliday et al. also included a visual discrimination group and a no-intervention control group. In their study, neither of these two groups nor the FD intervention group made any significant improvement on measures of phonological awareness and word reading.

It is important to note that the generalisation of AP training effects to language and reading ability has been reported in other studies (Merzenich et al., 1996; Miller et al., 2005; Moncrieff & Wertz, 2008; Sharma et al., 2012; Tallal et al., 1996; Temple et al., 2003). However, all of these studies have incorporated the use of speech stimuli in their training regimen, either as stimuli used in the training of AP ability or that reading and language interventions were included in addition to the AP intervention. Therefore, like the APD intervention studies discussed in Section 6.7.1.1, it seems difficult to determine whether the reported generalisation to language and reading in these studies was an isolated effect of the AP intervention.

Overall, the evidence to date does not support the notion that the **isolated** training of non-speech, AP ability improves reading and language in children SRD or SLI, with/without APD (whether these interventions should be considered as the sole intervention in APD management would depend on whether they have an impact on the daily, functional listening ability in children with APD. There is limited information on the effect that non-speech bottom-up interventions have on functional listening to date). The current findings seem to suggest that non-speech, AP interventions, on their own, produce very specific effects that are limited to the non-speech intervention task. This suggests that these interventions pose little functional benefits when used in **isolation**. However, as McArthur et al. (2008) postulated, the lack of generalisation does not exclude the possibility that training AP ability might improve the child's speech perception which may, in turn, result in better **readiness** to acquire reading and language, especially with more specific instructions or an intervention for reading and language. The idea of improved readiness for reading and language intervention is largely unexplored in the literature to date. This notion was explored in the present study. The findings suggest that prior FD intervention enhances the PP intervention outcome for phonological awareness, non-word reading and regular word reading. Phonological awareness, non-word and regular word reading are skills that pertain to the non-lexical reading process, where phonological awareness contributes to the ability to perform letter-sound conversions which is employed for the reading/decoding of non-words and regular words (Carrillo, 1994; Manis, Doi & Bhadha, 2000; Tunmer & Rohl, 1991). A discussion of these results is presented in Section 6.7.3.

Additionally, this lack of generalisation of the non-speech, AP intervention effect challenges the auditory deficit theory of SRD and SLI. It is widely accepted that not all children with SRD and SLI have AP deficits. One study reported that AP deficits were apparent in 42% of the SRD and SLI children in their sample (McArthur et al., 2008). For these two groups of children, the auditory deficit hypothesis suggests that SRD and SLI were caused by an AP deficit. If so, then remediating the underlining AP deficit should have led to improved reading and language processing. However, the current results showed that no improvement in reading or language was observed following improved AP.

In summary, the results of the present study show that despite significant intervention-specific improvement in FD, there was a lack of generalisation of this improvement to reading and language abilities. This finding is consistent with the findings of other studies that have investigated the generalisation effect of non-speech AP interventions (e.g., Halliday et al., 2012; McArthur et al., 2008). Therefore, the accumulating evidence to date does not support the use of non-speech, bottom-up interventions in **isolation** for the management of SRD, or SLI, with/without co-morbid APD. Further research is needed to explore the impact that these interventions have on functional listening in the APD population.

#### *6.7.2.3 Generalisation of the PP intervention effect to phonological awareness (the within-task generalisation)*

The results of the present study were inconclusive regarding the within-task generalisation of PP intervention to phonological awareness. On the one hand, there was significant improvement in the Phonological Awareness Composite Score of the CTOPP (CTOPP-PA-CS) after the PP intervention, due to improvements made by the three intervention groups that undertook the PP intervention. The CON group, who did not undertake the PP intervention, did not show an improvement in phonological awareness (see Figure 6.11 in Section 6.5.1.2.1). On the other hand, pair-wise comparisons of the difference score across Ax2 and Ax3 between the intervention groups and the CON group did not reach statistical significance.

The accumulated evidence to date shows that other reading interventions which target letter-sound correspondences have led to improvement in phonological awareness (Alexander, Anderson, Heilman, Voeller, & Torgesen, 1991; Blachman, Tangel, Ball, Black, & McGraw, 1999; Lundberg, Frost, & Petersen, 1988). For instance, Blachman et al. (1999) reported improvements in phonemic segmentation, letter sound, and letter name knowledge in a group of kindergarten children after a decoding intervention as compared to controls. Lundberg et al. (1988) also reported significant improvement in phonemic segmentation, syllable manipulation, and rhyming after a reading intervention that targeted decoding. However, these studies had sampled children with SRD and not those with APD. Hence, the inconsistency between the findings of these studies and the present one could be due to the difference in sampling. To date, there is limited research investigating the **isolated** effect that top-down interventions, such as the PP intervention, might demonstrate in the APD population (see Section 2.2.3.3). Clearly, more RCTs and well-designed studies are needed to explore the effectiveness of top-down interventions.

In summary, PP intervention was found to result in task-specific improvement. However, the findings were inconclusive regarding whether the improvement made during the PP intervention had generalised to another task of phonological awareness. Further research is needed to explore the effectiveness of top-down interventions in isolation in children with APD, generalisation effect of the PP intervention and to explain potential differences in intervention outcomes between the PP intervention and other computer-based reading interventions.

#### *6.7.2.4 Generalisation effects of PP intervention to word reading and receptive language*

There is partial evidence suggesting that PP intervention improved non-word reading but not the reading of irregular words. A large and significant effect size was found when comparing improvements made by the PP group and the CON group with regard to non-word reading (ALNLRAC-NW-ZS)[20], but not irregular word reading (the ALNLRAC-IW-ZS) (see Section 6.5.2.3). This finding is consistent with the fact that PP intervention predominantly targets letter-sound decoding rather than sight words. Non-word reading relies solely on the knowledge of letter-sound correspondences, i.e., the conversion of letters to sounds. However, irregular word reading largely depends on previous exposure to and familiarity with the word (Castles & Coltheart, 2004;

[20] The result of these comparisons did not reach statistical significance

Coltheart & Leahy, 1996). Therefore, the reading of irregular word is less related to the objectives of the PP intervention of target letter-to-sound correspondences (see Section 4.3.1 for more details).

PP intervention on its own also seemed to have limited generalisation to regular word reading. There was no significant difference or significant effect size observed for the comparisons of the change in performance in regular word reading of the PP group versus the CON group following PP intervention. However, the other two groups that also underwent the PP intervention (i.e., the FD-PP and the VD-PP groups) demonstrated significantly greater improvement in non-word **and** regular word reading after the PP intervention compared to the CON group. Again, this was not observed for irregular word reading. The greater improvement in non-word and regular word in the FD-PP group and the VD-PP group reading was observed after Phase 2 of the study period but not after Phase 1, suggesting that FD or VD intervention in isolation did not result in improvement in non-word and regular word reading, and that the improvements in non-word and regular word reading were only observed following PP intervention.

Previous research provides support for the effectiveness of similar reading interventions in improving non-word reading. Reading interventions that focus on the teaching of the letter-sound correspondences have been shown to be effective in improving reading ability, in particular reading via decoding (see Bus & van IJzendoorn, 1999; Ehri et al., 2001 for meta-analyses on the topic). Both meta-analyses concluded that reading interventions that target letter-sound correspondences were more effective than the reading interventions that focus solely on phonology.

Additionally, the PP intervention implemented in the present study was a computer-based program that also employs a multisensory approach to reading intervention. Previous studies also demonstrated the effectiveness of this approach (Ecalle et al., 2009; Joshi & Dahlgren M, 2002; Lynch et al., 2000; Magnan & Ecalle, 2006; Nicholson et al., 2000; Oakland, Black, Stanford, Nussbaum, & Balise, 1998; Simpson, Swanson, & Kunkel, 1992; Tijms, 2011). The use of multisensory cueing strategies is consistent with the studies that showed a multisensory integration and processing deficit in individuals with dyslexia (Facoetti et al., 2009; Hairston, Burdette, Flowers, Wood, & Wallace, 2005). Hairston et al. (2005) considered multisensory integration to be a critical part of reading development, because reading requires the efficient processing and accurate association of the associated auditory and visual language elements, e.g., the phoneme /t/ is associated with the grapheme ‘t’. These teaching strategies may strengthen phonological representation by connecting the associated information between the visual, auditory, and kinaesthetic senses that are related to the orthography-phonology elements.

Based on the above evidence, it seemed reasonable to expect that the PP intervention used in the present study would have demonstrated significant effect on non-word reading, like the other similar reading intervention programs. Therefore, there is a need to establish the generalisation effect of the PP intervention. However, it is important to note that, the all of the above studies were concerned with children with SRD and not APD. The inconsistency in the findings between the present study and previous research could also be due to the difference in sample.

The findings of the present study showed that the effects of PP intervention did not generalise to language measures. There were no significant improvements in receptive vocabulary (PPVT-SS) and sentence comprehension (TROG-SS) across all groups over the entire course of the study.

On possible explanations for the lack of generalisation of the PP intervention effect to language measures might be that language ability was not specifically targeted during the PP intervention (or the FD intervention) and therefore, no improved performance was to be expected. Additionally, this is consistent with the results of other studies that have demonstrated the differential effects of other PP interventions and language interventions. In other words, PP interventions result in improvement on PP measures and language interventions on language measures; there is minimal generalisation of the PP intervention effect to language measures and vice versa (Bowyer-Crane et al., 2008; Gillon & Dodd, 1995; Strehlow et al., 2006; Tyler & Sandoval, 1994).

For instance, Bowyer-Crane et al. (2008) compared the effects of an oral language intervention and a phonological reading intervention in children with language impairment. The researchers found that the children who underwent the phonological reading intervention showed better literacy and PP outcomes, whilst the children who underwent the language intervention demonstrated better vocabulary and grammatical skills. The lack of generalisation between PP interventions and language interventions was also reported in Gillon and Dodd (1995) and Tyler and Sandoval (1994).

Another explanation is that most children in the current sample already had age-appropriate language ability at the beginning of the study. For instance, among the participants of Study 2, only one participant was found to have poor[21] receptive vocabulary (a member of the FD-PP group) and another six children were found to have poor sentence comprehension (one in the FD-PP group, two in the VD-PP group, one in the PP group, and two in the CON group). Since most children showed age-appropriate language ability prior to the commencement of any intervention, there might have been a ceiling effect on the two language measures, leaving little room for demonstrating improvement in the standard scores for the PPVT or the TROG.

In summary, there is partial evidence suggesting that PP intervention had an effect in improving non-word and regular word reading, but not irregular word reading. This pattern of results is consistent with the object of the PP intervention. There was a lack of generalisation to language. This supports the notion that any of the observed PP intervention effects discussed above was specific to the PP intervention and not due to repeated testing or maturation.

### 6.7.3 The effects that prior FD intervention has on the outcomes of PP intervention

As discussed in Section 6.7.2.2, researchers have postulated that non-speech AP interventions, such as the FD intervention in the present study, could improve children's speech perception and consequently resulting in better readiness to learn reading. This was explored in the

[21] Poor ability was defined by a standard score below the -1SD of the mean for age.

present study and it was hypothesised that prior FD intervention would result in enhanced PP intervention outcomes for the FD-PP group compared to the other groups.

#### *6.7.3.1 Effects of prior FD intervention on the PP intervention-specific effect*

The results showed that prior FD intervention did not seem to lead to enhanced PP intervention-specific outcomes for the FD-PP group. There was no significant difference between the FD-PP group and the PP group with regard to the PP Intervention Specific Literacy Score (see Section 6.6.1).

One explanation for this non-significant result might be that PP intervention, on its own, already resulted in a large intervention-specific effect, thus it might be difficult for additional interventions to demonstrate further detectable effects on this measure. The effect size obtained from the comparison between the change in the PP Intervention-Specific Literacy Score of the PP group versus the CON group was A = 1.00, and this was the ceiling level of maximum effect for Vargha A. The effect of improved FD ability on the intervention-specific effect of reading interventions has not been previously investigated. The results of the present study suggest that prior FD intervention did not enhance the intervention-specific effect of reading-related intervention. However, further research is needed to replicate this finding before firmer conclusions can be drawn.

#### *6.7.3.2 Effects of prior FD intervention on phonological awareness*

Despite the lack of generalisation to reading, there are preliminary indications that prior FD intervention has an enhanced effect on the phonological awareness outcome of PP intervention. The group that received prior FD intervention showed significantly greater improvements in phonological awareness across the duration of the study compared to the VD-PP, PP and CON groups. This is noteworthy as there was an absence of group differences in the phonological awareness composite score prior to the undertaking of any interventions. Nevertheless, the finding that prior FD intervention enhanced the phonological awareness outcome of the PP intervention is only preliminary due to the lack of significant interaction and significant differences in the between-group comparisons.

#### *6.7.3.3 Effects of prior FD intervention on word reading abilities*

Prior FD intervention seems to have an isolated enhancing effect for the skills associated with the non-lexical reading process following PP intervention. The FD-PP group showed greater improvement than the PP group for phonological awareness, non-word, and regular word reading after PP intervention, but not for irregular word reading (see Section 6.5.2.3 and Section 6.6.3). As mention before, phonological awareness, non-word reading, and regular word reading are all abilities associated with the non-lexical reading process, whereas irregular word reading depends on lexical reading and other cognitive processes (see Section 5.7.3). Hence, the results of STUDY 1 are consistent with the findings of STUDY 2, i.e., STUDY 1 demonstrated that children with FD difficulty showed poorer non-lexical reading ability than children with age appropriate FD, but both groups showed similar lexical reading ability; STUDY 2 demonstrated that improved FD ability can enhance the non-lexical reading outcome of PP intervention but had limited effect on measures associated with lexical word reading.

The notion of FD being a contributing factor to the non-lexical reading process needs to be re-explored by future research. One of the limitations of the present study is that the PP intervention largely targets the non-lexical reading process rather than the lexical reading process, i.e., one of the main objectives of the PP intervention was to strengthen letter-sound correspondences and decoding skills. Sight words were included in the PP intervention but as a lesser component. Therefore, the lack of combined FD and PP intervention effect on irregular word reading could also be because PP intervention had limited isolated effect on lexical reading in addition to a lack of enhancing effect from prior FD intervention. Further research could consider utilising a reading intervention that target both the non-lexical and the lexical reading process to a similar extent in order to further explore the enhancing effect of prior FD intervention.

Interestingly, prior VD intervention also seemed to have enhanced the PP intervention effect for non-word and regular word reading as prior FD intervention did. The VD-PP group also demonstrated significantly greater improvement than the PP group on non-word reading and regular word reading, both prior FD and VD interventions had enhanced the outcome of PP intervention for non-word and regular word reading to a similar degree.

One explanation might be that the FD and VD interventions had primed the FD-PP group and the VD-PP group for the subsequent PP intervention. Prior exposure to a computer intervention program might have positively affected the children's engagement and participation during the subsequent PP intervention. In other words, it could be that those who had undergone the more monotonous FD or VD intervention were: 1) already familiar with computer-based interventions; and 2) seem to respond to the shift from a relatively monotonous computer program to a software program that was perceived to be more enjoyable or fun. The more meaningful and engaging nature of the PP intervention may have been more motivating and interesting. Therefore, children in the FD-PP and the VD-PP groups could have had greater engagement duration the PP intervention which could have led to greater intervention outcomes. This interpretation is supported by the fact that the parents of the children in the FD-PP and VD-PP groups often reported that their child found the PP intervention fun and enjoyable. The children in the FD-PP and the VD-PP groups required minimal coaxing and support during the PP intervention phase. However, the parents of the children in the PP group often reported that their child found the PP intervention laborious, and coaxing and other means of reinforcements were needed to help their child to undertake the training.

Another possible explanation could be that the FD or VD intervention had an effect on improving attention. The effect that attention might have on intervention outcomes has been documented in previous studies. For instance, Gillam et al. (2008) found that children who undertook an academic enrichment program that did not target language abilities made similar significant improvement on language and backward masking measures as the participants who had undertaken language and AP interventions (see Footnote 3, pp. 25 for more details). This finding was unexpected. One explanation offered by the authors was that undertaking the academic achievement program had a positive effect on the children's attention and overall information-processing ability which might have led to better performance during the post-intervention testing.

However, what the above discussion cannot explain is that both prior FD and VD interventions resulted in significantly greater improvement for non-word and regular word reading than the isolated effect of PP intervention, but only prior FD intervention resulted in greater improvement in phonological awareness, and VD intervention did not. This differential intervention effect could not be explained by the potential effects of prior exposure to a more monotonous computer intervention program as discussed above.  This is because the effects that are related to the prior exposure to another intervention should result in improvement across all measures, i.e., greater improvement for phonological awareness should have been observed in the VD-PP group as compared to the PP group following PP intervention as well but this was not the case (see Section 6.5.1.2.2). In fact, the VD-PP group had undertaken a longer duration of VD intervention than the FD-PP group had with the FD intervention during Phase 1 (see Section 6.2). Therefore, if the greater improvement observed in the FD-PP and VD-PP groups were due the prior exposure to another intervention, then the VD-PP group might even demonstrate greater improvement than the FD-PP group. Hence, it seems unlikely that the differential enhancing effect of the FD and VD interventions on PP intervention outcomes was due to prior exposure to another intervention.

Another explanation could be that the VD intervention had some independent effect in enhancing the word reading outcome of PP intervention, but not for phonological awareness. VD intervention might have resulted in improved visual processing which could have contributed to the strengthening of orthographic processing, and in turn facilitated the learning of the orthography-phonology associations which was targeted during PP intervention. This resulted in greater improvements in non-word and regular word reading. This interpretation is consistent with findings of the studies that have demonstrated that poor visual processing can contribute to reading difficulties (Cestnick & Coltheart, 1999; Eden et al., 1996; Demb, Boynton & Heeger, 1997; Lovegrove, 1991; Lovegrove & Williams, 1993; also see Farmer, 1995 for a review regarding visual processing and reading). However, improved visual processing did not enhance the PP intervention outcome for phonological awareness because phonological awareness is largely auditorily based.

One could argue that if prior VD intervention improves visual processing then there should be improvement across all word reading measures including irregular word reading, which largely depends on visual processing and orthographic processing. Again, the lack of enhancing effect of prior VD intervention for irregular word reading could be because PP intervention in isolation also demonstrated limited effect for irregular word reading. The main aim of PP intervention was to target letter-sound associations and facilitate decoding skills. PP intervention in isolation has demonstrated limited generalisation effect on irregular word reading (see Section 6.5.2.3). Therefore, the added benefit of improved visual processing could not enhance this limited effect to a measurable degree.

In summary, prior FD intervention might have enhanced the outcome of PP intervention through improving AP - specifically FD, while prior VD intervention might have enhanced the outcome of PP intervention through improving visual processing. Both prior FD and VD interventions had resulted in greater improvement in letter-sound decoding and non-lexical reading than the effect of PP intervention in isolation. However, prior FD intervention resulted in an additional effect for improving phonological awareness. The differential effects of prior FD and VD intervention provide evidence that the observed effects were indeed due to the two interventions independently.

### 6.7.4 Conclusion

The results of STUDY 2 demonstrate that FD difficulty can be improved by training. This was unrelated to the effect of the intensive exposure to a computer-based intervention program. Additionally, the effect of training can be observed when reassessed 6 weeks and 12 weeks after the training. However, such gains appear to be specific to the intervention task and there was a lack of generalisation to another FD task, or to word reading and language measures. The PP intervention also demonstrated significant intervention-specific effect which was maintained 6 weeks after the intervention. However, there is only partial evidence for its generalisation to phonological awareness and word reading. Prior FD intervention resulted in improvement in phonological awareness, non-word reading, and regular word reading that was significantly greater than the isolated effect of the PP intervention. These findings are consistent with the findings of STUDY 1 that showed that FD might be a contributing factor to the non-lexical reading process. They also support the hypothesis that FD intervention could improve children's readiness to acquire the more complex skill of reading upon subsequent reading intervention.

However, prior VD intervention also appeared to have an enhancing effect on the non-word and regular word reading outcomes of PP intervention but not for phonological awareness. A possible explanation might be that VD intervention had resulted in improvement in visual processing, which in turn improved orthographic processing and facilitated the learning of letter-sound associations and decoding skills which was targeted during the PP intervention. VD intervention did not have an enhancing effect for the PP intervention outcome of phonological awareness because phonological awareness is largely auditory in nature. This proposition remains tentative and needs to be formally tested. Further studies could consider including measures of visual processing to determine whether improvement in visual processing is indeed achieved and to further explore which aspects of visual processing are contributing to the greater improvement in non-word and regular word reading.

# 7 GENERAL DISCUSSION

The focus of the present thesis was to investigate the effectiveness of bottom-up and top-down interventions for children with APD. STUDY 1 sought to investigate whether there were significant differences between the PP ability, word reading ability, receptive language skills, auditory sustained attention, and executive control of children with APD who also demonstrated FD difficulty, and those with APD but without FD difficulty. The aims of STUDY 2 were to investigate the outcomes of two intervention programs in children with APD, when administered individually and when administered in combination. The interventions were: 1) a computer-based training program to improve FD, the SoundsPod (McArthur et al., 2008), referred to as the 'FD intervention', and 2) a computer-based intervention program to improve phonological processing, the Reading Sounds 1Pro (Rajkowski, 2003), referred to as the 'PP intervention'. An important focus was to investigate whether prior FD intervention would enhance the outcome of the subsequent PP intervention.

The findings of STUDY 1 suggest that children with APD who also showed FD difficulty demonstrated significantly poorer phonological awareness, non-word and regular word reading than children with APD who demonstrated age-appropriate FD. However, there were no group differences for rapid naming, phonological memory, irregular word reading, receptive language, auditory sustained attention and executive control. These findings suggest that FD mostly affected the non-lexical reading processing rather than the lexical reading processing and language processing in the current sample.

The findings of STUDY 2 showed that FD intervention demonstrated significant intervention-specific effect. However, there was no significant generalisation effect to a similar FD task or to other cognitive abilities. PP intervention also demonstrated significant intervention-specific effect; there was partial evidence that its effect generalised to a similar task of phonological processing, specifically tasks concerning phonological awareness. There was also partial evidence for its generalisation to non-word and regular word reading. However, there was no generalisation of the PP intervention effect to irregular word reading and receptive language. Lastly, the findings provide evidence suggesting that prior FD intervention had an enhancing effect on the PP intervention outcome of phonological awareness, non-word, and regular word reading which are skills are associated with non-lexical reading.

## 7.1 Interrelationship between FD, SRD and SLI

The findings of the present studies are consistent with previous research suggesting that FD is an AP ability that is important to reading. Extending from previous research, the present findings show that FD was more concerned with the non-lexical reading process rather than the lexical reading process. This is consistent with the notion that non-lexical reading relies more on AP abilities to learn and apply letter-sound correspondences than lexical reading which might be more dependent on word exposure, visual word recognition amongst other cognitive abilities. Figure 7.1 shows a model that depicts a possible representation of the interrelationship between FD, other AP abilities and reading. The green, shaded oval shows that FD mainly contributes to the non-lexical reading process. This shaded oval is embedded inside a bigger oval that encompasses other AP abilities which might also have an effect on non-lexical reading. AP abilities might also contribute to other aspects of reading, including the lexical reading process, but their effects on lexical reading are likely to be smaller (depicted by the green dotted line) as lexical reading might be more dependent on word exposure and other cognitive processing abilities. It is important to note that although in this simplistic model that the ovals depicting the effect of FD and AP abilities completely enclosed the Grapheme-Phoneme Rule System, FD and other AP abilities are not the sole skills that contribute to the learning and application of letter-sound correspondences. Other skills are also involved, such as visual processing and memory, but these skills are not depicted here as this model is mainly illustrating a possible representation of the interrelationship between FD and reading.

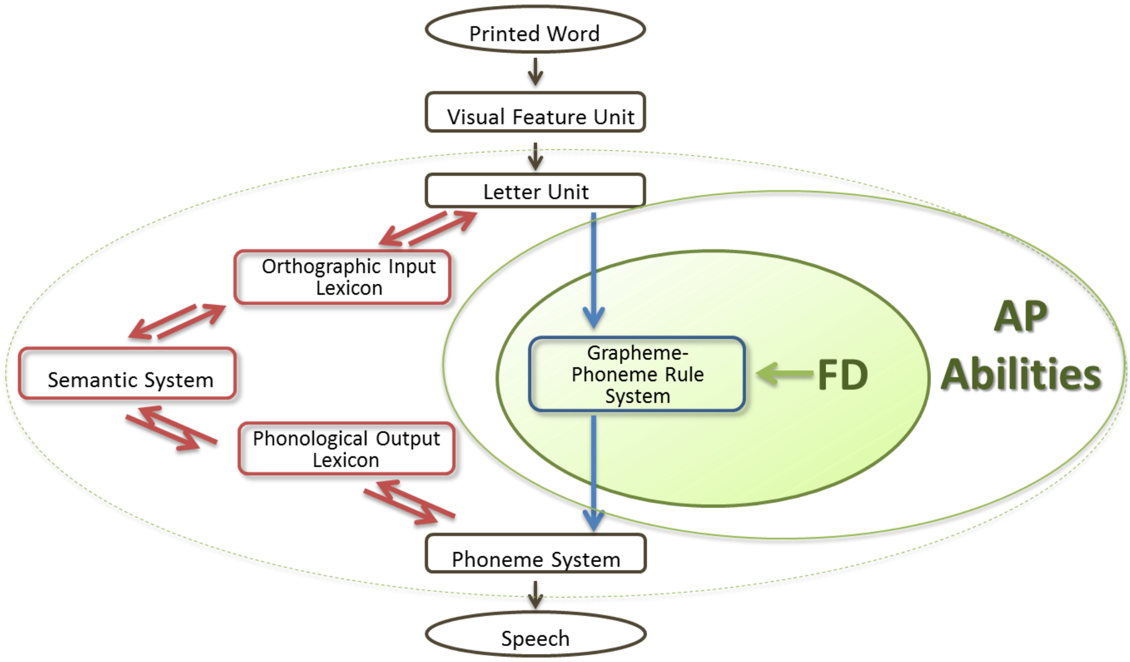


**Figure 7.1: A model depicting a possible representation of the interrelationship between FD, other AP abilities and reading.**

The present findings are also in partial agreement with the *RAP deficit hypothesis* (Tallal, 1980) in that AP deficits could contribute to reading difficulty. However, instead of a deficit in RAP, the present findings demonstrate that another AP ability, namely FD, could contribute to reading difficulty. Additionally, the present findings do not provide support for a causal relationship between AP deficits alone and reading difficulty like the RAP deficit hypothesis postulates. The present findings suggest that poor FD might be *one of the contributing factors* to poor non-lexical reading. If FD difficulty alone could result in poor non-lexical reading outcome, than one could hypothesise that improved FD after undertaking FD intervention would result in improved non-lexical reading. However, the present findings show that despite significant improvement in FD after the FD intervention, the FD-PP group (in which four of the five participants achieved age-appropriate FD ability after the FD intervention) showed no improvement on the tasks related to non-lexical reading. Such an improvement was only observed in the FD-PP group after its participants had undertaken the PP intervention. This demonstrates that it is unlikely that poor FD was a sole causal factor to non-lexical reading difficulty.

Lastly, the present set of data is insufficient for drawing affirmative conclusions with regards to the interrelationship between FD and language. The present findings do not provide support that FD contributed to language ability. However, there were relatively few children with language difficulties in the current sample. Therefore, further research involving children with SLI and FD difficulty would be needed to further investigate whether FD contributes to language ability.

## 7.2 Limitations of the present studies

Overall, the findings of the two studies presented in this Thesis should be interpreted with some cautions. There were a number of potential limitations that should be taken into account when considering the results of this research:

1. Small sample size. The small sample size may have led to type II errors. Therefore, it could be that some effects were not detected due to insufficient statistical power. Multiple efforts were made to enhance recruitment. However, one of the participating clinics withdrew their participation in the research, which had a substantial negative impact on the recruitment process.
2. Multiple testing. There is an increased probability of type I error due to multiple testing. The use of the Bonferroni procedure and other methods of adjustment for multiple comparisons were considered. However, they were not implemented because they substantially reduce statistical power and further exacerbate type II errors (Holm, 1979; Jennions & Møller, 2003; Nakagawa, 2004; Perneger, 1998; Rice, 1989). Due to the exploratory nature of the present study, it was intuitive to place the emphasis on reducing type II errors. Therefore, the present thesis has attempted to maximise the probability of identifying potential factors that could co-exist with FD difficulties (STUDY 1) and the potential intervention effects associated with FD intervention and its effects on a subsequent reading intervention

(STUDY 2). These findings should be considered as preliminary findings and should be replicated before a definite conclusion can be drawn.

3. Generalisation. Children with APD participating in STUDY 2 showed poor FD and PP. Therefore, it is uncertain that the findings of the current two studies can be generalised to: 1) all children with APD, including children with APD who do not demonstrate poor FD; and 2) poor readers without APD, in regard to the finding of a possible link between poor FD and poor reading.
4. Procedures regarding the SoundsPod. The use of the SoundsPod program in the present study followed the procedure outlined in McArthur et al. (2008), with one exception. During the recruitment phase, McArthur and colleagues tested children a second time when their results showed an elevated FD threshold score and large variability within the run, i.e., if the SD was greater than 30 Hz. If the child then produced a normal threshold and a SD lower than 30, the child was considered as having age appropriate FD. If the child's threshold remained elevated, they were considered as having FD difficulty. During the recruitment phase of the present study, children were required to do the task only once. If their threshold score was elevated, even when there was large variability within the run, they were considered as having FD difficulties. Therefore, there is the possibility that there were children who were considered to demonstrate FD difficulties in the current study who actually had age-appropriate FD, but had a poor one-off performance on the SoundsPod. The reason for the protocol used in the present study was to minimise exposure to the task prior to the training phase of the study as an attempt to maximise the training effect. Additionally, performance on this task was to be compared to the performance on another FD task that was intended to measure the generalisation of the FD intervention effect in the intervention study (i.e., Study 2 of the current thesis), so there was a need to standardise the protocol of both tasks. The test procedure of the other FD task (i.e., the Dinosaur Task) in previous research studies (Halliday & Bishop, 2006; Hill et al., 2005; Mengler et al., 2005)

was that the participants completed the task once during the assessments (see Section 5.8.1 for a description of the Dinosaur Task).

## 7.3 Implications for clinical practice

It is currently recommended that interventions for APD should include both bottom-up and top-down approaches, although evidence for greater effectiveness of a combined approach was lacking. The findings of the present study suggest that non-speech, bottom-up interventions should not be the sole intervention for children with APD. Non-speech, bottom-up interventions, such as the FD intervention, might be effective in producing intervention-specific improvements, but the acuminating evidence suggests that when administered in isolation, they produce limited generalisation effects to other AP tasks that targeted the same AP ability, as well as to more complex cognitive abilities, such as reading or language. The lack of generalisation within-task and across-task questions whether bottom-up (non-speech) interventions **on their own** would result in any observable functional changes for children with APD.

Interestingly, when non-speech , bottom-up FD intervention was followed by a top-down intervention that specifically target reading, it enhanced the effect of the reading intervention and produced improvements that were greater than just undertaking the reading intervention alone. This provides evidence in support of the recommendation that **both** bottom-up and top-down interventions should be incorporated in APD management. When administered one after another (i.e., bottom-up intervention followed by top-down intervention), bottom-up interventions might improve speech perception by remediating the underlying AP difficulties, and hence resulting in improved readiness to learn the more complex skills of reading and language upon subsequent specific reading and language interventions (McArthur et al., 2008). Therefore, it is important to maintain a close collaboration between the audiologists who diagnose APD and the other professionals who are involved in the management of APD (e.g., the speech pathologists, psychologists, educators). This will allow the professional who is delivering the intervention to have an in-depth understanding of the child's AP difficulty, and hence, could better incorporate bottom-up AP interventions into the broader management of the child's communication/academic difficulty, given the potential enhancing effect that the AP intervention might have on the child's communication/academic outcomes.

Consistent with previous research (Ahissar et al., 2000; Baldeweg et al.,1999; De Weirdt, 1988; Talcott et al., 2002), the findings of the present studies demonstrate that FD is an important AP that is related to non-lexical reading ability. Therefore, children with/without APD who demonstrate reading difficulties, especially difficulties that are related to non-lexical reading, would benefit from an assessment of their FD ability. If the child's FD was poorer than what was deemed as age-appropriate, FD intervention could be undertaken prior to the reading intervention, which might enhance the outcome of the reading intervention.

Lastly, FD intervention may benefit some children with FD difficulty and not others. Although significant differences were observed when analysing group data, informal evaluation of the data showed that different children responded to the FD intervention differently. Most of the participants who undertook the FD intervention made marked improvement in their FD threshold scores; nevertheless, a minority of participants did not respond to the intervention as well as their peers. Similar observations have been noted in previous studies (Alexander & Frost, 1982; Halliday et al., 2008; McArthur & Hogben, 2011; Roach, Edwards, & Hogben, 2004). Further research is needed to identify the factors that might affect FD intervention outcomes.

## 7.4 Suggestions for further research

Future research on the effects of FD intervention could consider replicating the two studies presented in the present thesis with a larger sample size. This would provide further empirical evidence to confirm the findings of these studies. The priori power analysis showed that based on a statistical analysis using an ANOVA with four experimental conditions and repeated measures of four observations with both within- and between-factor analyses, a total sample size of 36 participants were needed to detect a medium effect size (f = 0.25) with a power of 80%, and a hypothesised type I error of $\alpha = 0.05$. Therefore, a sample size greater than 36 would be helpful in reducing risk of Type II errors and allow for the detection of intervention effects that have smaller effect sizes. Future studies could also consider sampling children who have specific difficulties with phonological awareness or non-word reading rather than PP in general. This is because the findings of Study 1 demonstrate that FD ability is specifically associated with phonological awareness and non-word reading, and not to other abilities that constitute PP, i.e., phonological memory and rapid naming.

Additionally, future studies that investigate the intervention outcomes in children with APD could consider including additional repeated testing of attention and executive control. Although, the differential effects of FD and VD interventions suggest that the observed effects were likely specific to the individual interventions rather than due to improvements in more global processes, such as attention and executive control. However, such an observation needs to be formally tested.

Additionally, studies could consider investigating whether undertaking six weeks of non-speech AP intervention followed by six weeks of reading intervention has greater intervention effects than undertaking 12 weeks of reading intervention for children with APD. Future studies could also explore whether undertaking both bottom-up and top-down interventions concurrently would result in similar enhancing effect as undertaking bottom-up interventions prior to top-down interventions.

At the time of the current thesis, the use of psychoacoustic tasks, such as the SoundsPod, the Dinosaur task and the ones documented in Moore et al. (2010), to assess AP abilities is still in its infancy. The psychometric properties of most of these tasks have not yet been established. Future studies could consider investigating the reliability and validity of these tasks. They could also consider standardising these assessments with normative data for age-appropriate abilities.

Moreover, future studies could also consider investigating the effects that FD interventions have on language ability. Previous research has demonstrated that FD can be associated with SLI

(Hill et al., 2005; McArthur & Bishop, 2004). The results of the current research did not provide support for this position. This could be because the current sample did not include many participants with SLI. Therefore, future studies in this area could consider including SLI as an inclusion criterion. Furthermore, a language-based intervention could succeed the FD intervention to evaluate whether the prior intervention has any effects on the outcome of the latter.

Further research is also needed to investigate whether the prior training of other AP abilities has any enhancing effects on the intervention outcomes of subsequent reading or language intervention. One such AP might be RAP. Previous studies have shown that non-speech RAP intervention on its own did not result in improvements in reading or language abilities (e.g. McArthur et al., 2008). However, this notion of undertaking RAP intervention prior to a reading or language intervention and enhancing its effects has not been tested.

Lastly, future research could also consider evaluating the effect that a prior visual discrimination intervention has on reading intervention outcomes. The current research demonstrated that VD intervention has some effect on enhancing word reading ability. Therefore, it would be interesting to investigate this in a more comprehensive manner by recruiting participants with visual discrimination difficulties and investigating other aspects of reading that are thought to link to visual discrimination, e.g., reading speed and letter perception.

## 7.5 Conclusion

The findings of the studies in the present thesis support the recommendation that APD intervention should include both bottom-up and top-down approaches. It also supports the proposition of McArthur et al. (2008) that bottom-up interventions could improve AP abilities, which in turn improve speech perception and the readiness to acquire the more complicated abilities of reading and language upon subsequent top-down interventions that target reading and language specifically.

Extending from previous research, the findings of the present studies demonstrate that FD co-existed with difficulty of non-lexical reading rather than lexical reading. Furthermore, FD intervention that was administered prior to the PP intervention showed an enhancing effect for the outcome of the PP intervention that was specific to phonological awareness and non-word reading.

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# APPENDICES

## APPENDIX A: PARTICIPANT INFORMATION SHEET

Dept. of Speech Pathology and Audiology
Flinders University, Adelaide
GPO Box 2100
Adelaide SA 5001

25th July 2011

Dear Parents/ Guardians,

You and your child are invited to take part in a research project aiming to compare how well different treatment programs for Auditory Processing Disorder (APD) work. You have been contacted because your child has been diagnosed with APD at either the Flinders University (at Flinders Medical Centre, FMC) or Adelaide Hearing Consultants APD clinics. Your involvement in this study is completely voluntary. Whether you take part or not, the services that you receive at Flinders University, FMC or Adelaide Hearing Consultants will not be affected in any way.

This research will be conducted by Ms Emilie Lam, a current PhD candidate, supervised by Dr Willem van Steenbrugge, Dr Christopher Lind and Dr Sarosh Kapadia who are all Senior Lecturers in the Department of Speech Pathology and Audiology at Flinders University. This project is part of Emilie's PhD Study.

We are inviting children who have been diagnosed with APD in the past one year and have reading difficulty to take part in this study. This project aims to evaluate the effectiveness of different forms of training in helping children with APD to learn to read.

Unfortunately, your child will not be able to participate in the study if English is their second language, or if there are any known diagnoses of chronic medical conditions, such as epilepsy, cerebral palsy, autism spectrum disorder, pervasive developmental disorder, intellectual disability, history or head injury or other major sensory impairments, such as severe visual impairment (excluding regular requirement of glasses) and/or peripheral hearing loss, and if they are undergoing concurrent therapy for APD and reading.

Should you agree to participate, your child will attend an initial assessment, which can take place at the Speech and Hearing Clinic at Flinders University, or alternatively, at a quiet room at home depending on your preference. During this assessment, your child will undertake hearing and vision screening, and testing for non-verbal IQ, auditory perceptual ability, reading, language and attention. Feedback regarding your child's ability will be provided at the end of the assessment session. This will take approximately 3 hours.

If your children's ability matches the requirement of the study, your child will be randomly assigned to one of four groups. The training that the groups undergo will be different but all trainings are designed to facilitate auditory processing and reading skills. All training programs are computer game-based and will be carried out at home. The training programs will be loaded onto your family's home computer. Your child would need to play the game for 30 minutes a day, four days a week for six weeks or for 12 weeks depending on the group that they are assigned to. We are interested to see how the different treatments can improve children's auditory processing, language and literacy skills. Please note that all treatment is free of charge.

Additionally, depending on the group that your child is assigned to, treatment will commence at different times, ranging from immediately after the first assessment to 4 to 5 months later. This waiting period is very important because it allows us to monitor natural changes in the children's ability over a period of time.

All children will undergo 3 additional assessments (at 6 weeks, 12 weeks and 18 weeks after the first assessment) to look at changes in their auditory perceptual skill, reading, language and attention. These follow-up assessments will take approximately 2.5 hours to complete and can take place at the Speech and Hearing Clinic at Flinders University, or alternatively, at a quiet room at home depending on your preference.

The findings of this research will increase our knowledge of APD and provide information which will help speech pathologists and audiologists in managing APD effectively. You will be reimbursed for any incurred travel expenses.

We have taken all possible measures to eliminate any foreseeable risk for your child's involvement in the project. All assessments use in the study are standard assessments which are widely used in speech pathology and audiology clinics and in research. All training programs are designed for and have been used with children in previous research or in clinical practice. Should you have any enquiries, please feel free to contact Emilie or one of her supervisors via the contact details below.

Under Australian privacy law all information collected about you must be kept confidential, unless you agree to it being released. If you consent to take part in this study, your child's medical records and the data collected for the study will be looked at by the research team. The team will have a duty of confidentially to your child as a research participant and no information that could identify you or your child will be given to anyone else. If the results of this study are published, for example in scientific journals, you will not be identified by name.

Records and data about your participation in this study may be used for the purposes of this study, or for further analyses in the future. All such records and your right to them will be protected in accordance with Australian law.

Finally, the Flinders Clinical Research Ethics Committee requires us to make the following statement: If your child suffers injury as a result of participation in this study, compensation might be paid without litigation. However, such compensation is not automatic and you may have to take legal action to determine whether payment should be made.

The findings of this study will be published in Emilie's PhD thesis, conference paper, journals and other related publication at a later date without your child being identified in the publication in any form or manner. You may receive a summary of our research findings on request.

You will have the right to withdraw from the study at any time without giving a reason. This will not affect the standard care or treatment you will receive from Flinders Medical Centre, Flinders University and Adelaide Hearing Consultants.

If you would like to take part in this study, please fill out the accompanying Consent Form and return it via the envelope included. Alternately, if you do not wish to take part or be contacted regarding the study, please notify Emilie via email address provided below. Please free feel to contact the investigators if you have any other concerns or should you require further details about the project.

Ms Emilie Lam
lam0043@flinders.edu.au
0430 562308

Dr Willem van Steenbrugge (PhD)
willem.vansteenbrugge@flinders.edu.au
(08) 8204 5942

This study has been reviewed by the Flinders Clinical Research Ethics Committee. If you wish to discuss the study with someone not directly involved, in particular in relation to policies, your rights as a participant, or should you wish to make a confidential complaint, you may contact the executive officer on 8204 4507 or email research.ethics@health.sa.gov.au.

Yours sincerely,

PhD Candidate
Department of Speech Pathology and Audiology
Flinders University of South Australia

## APPENDIX B: CONSENT FORM

**Southern Adelaide Health Service / Flinders University**
**HUMAN RESEARCH ETHICS COMMITTEE**

**CONSENT BY A THIRD PARTY TO PARTICIPATION IN RESEARCH**

I, ........................................................................................................ request and give
*(first or given names)* *(last name)*

consent to ........................................................................................................
........................................................................................................'s
*(first or given names)* *(last name)*

involvement in the research project: **The effectiveness of auditory perceptual and phonological training in remediating reading difficulties in children with Auditory Processing Disorder (APD)**.

I acknowledge the nature, purpose and contemplated effects of the research project, especially as far as they

affect ........................................................................................................
*(first or given names)* *(last name)*

have been fully explained to my satisfaction by ..............................................
*(first or given names)* *(last name)*

and my consent is given voluntarily.

I acknowledge that the detail(s) of the following has/have been explained to me, including indications of risks; any discomfort involved; anticipation of length of time; and the frequency with which they will be performed:

1. Involvement in this project requires my child to attend an Initial Assessment which will take 3 hours to complete and that he/she may continue to take part in the study if he satisfy the requirements for the study.
2. Should we continue our participation, my child will undertake 3 more sessions of assessment. They will each take approximately 2.5 hours to complete and may take place at my home or at the Speech and audiology clinic at Flinders University.
3. Depending on which group my child is being assigned to, treatment may commence immediately after the initial assessment or at a later date (waiting period can be up to 5 months).
4. My child will receive daily treatment sessions, 30 minutes per day, 4 days a week for 6 weeks or 12 weeks depending on the group that he/ she is assigned to.
5. I will be reimbursed for any incurred travel expenses.

I have understood and am satisfied with the explanations that I have been given.

I have been provided with a written information sheet.

I understand that ........................................................................................................ 's involvement in

*(first or given names)* *(last name)*

this research project 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.

I declare that I am over the age of 18 years.

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 to determine whether he/she should be paid.

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Signature of parent, legal
guardian or authorised person: .................................................................. Date: .....................

Relationship to subject: ..........................................................................................................

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**I assent to taking part in this study**

Signature of subject: ..................................................................................... Date: .....................

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I, .................................................................. have described to ...................................................
the research project and nature and effects of procedure(s) involved. In my opinion he/she understands the explanation and has freely given his/her consent.

Signature: ............................................................................................................ Date: .....................

Status in Project:..........................................................................................................................

## APPENDIX C: PERSONAL DETAILS FORM

Dept. of Speech Pathology and Audiology
Flinders University, Adelaide
GPO Box 2100
Adelaide SA 5001

Contact Details

Thank you for your interest in this study. Please complete and return this form with the consent form in the prepaid envelope provided.

Name of Child:____________________________________________

Name of Parent/Carer:_______________________________________

Child's DOB:______________________________________________

Phone Number:____________________________________________

Email:___________________________________________________

Address:__________________________________________________

__________________________________________________________

______________________________________________

APD Assessment Date:_______________________________________

Name of Clinic:____________________________________________

Was your child diagnosed with APD: Yes ❑ No ❑

Has your child been diagnosed with other developmental conditions?

__________________________________________________________

__________________________________________________

Where did you get to know about this study?

_____________________________________________________