The Development of a Functionally Representative Framework for the Assessment and Support of Students with a Vision Impairment through Education

By

Lynne Loh

Thesis

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Summary

All students have equal rights to a quality education and learning, however, for students with a vision impairment, access to class materials and therefore educational outcomes can be negatively impacted by their vision impairment. Previous studies have demonstrated that students with a vision impairment do not perform at the same level as their normally sighted peers with respect to reading, in terms of speed but not overall ability, and early intervention can support improved educational outcomes.

Vision function is the measurement of the working ability of the eyes and visual system that can be assessed with measures of visual acuity, visual fields, and ocular motor balance. Functional vision describes the way in which the eyes and vision perform during visually guided tasks, such as reading, watching television, or playing sports. Support for children with a vision impairment, within the classroom environment, is typically based upon measures of vision function, which do not truly reflect of the student's actual visual ability.

This thesis investigates the functional visual capabilities of students with vision impairment within their educational environment in South Australia, challenging the existing reliance on visual acuity as a proxy for functional vision in classroom settings. This thesis will question the adequacy of visual acuity to fully capture a student's functional vision in the classroom.

Over 250 students with a vision impairment, aged 5-18 years, are supported by specialist vision teachers within the South Australian School and Services for Vision Impaired (SASSVI) under the

South Australian Department of Education. The South Australian School for Vision Impaired caters to children with more severe VI, while those with less severe impairments are integrated into mainstream education. Support eligibility is solely based on clinical measures of VA and visual field extent.

The thesis highlights the complexity of childhood vision impairment and the functional impact, which varies depending on the cause of vision loss and environmental conditions. This can result in significant challenges understanding the functional implications of vision impairment within a classroom environment. From these findings a new and comprehensive assessment framework to tailor classroom support around an individual's functional vision, thereby enhancing curriculum accessibility is proposed. This framework incorporates a holistic approach by integrating reading performance, visual search, visual processing, and the impact of pathologies, including nystagmus. It also includes educational interventions to increase students' understanding of their vision impairment, empowering them to advocate for themselves.

The outcome of this work is impactful. For educators and vision specialists, it provides a comprehensive tool for assessing and supporting students with a vision impairment. For policymakers, it presents empirical evidence to reconsider existing guidelines and practices. Most importantly, for students with VI, it promises a more inclusive and equitable educational experience, ensuring that their unique visual needs are understood and adequately addressed in the classroom.

DECLARATION

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

Signed:

Date: 24th November 2023.

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List of publications and abstracts arising from this thesis

Publications

Loh L, Prem-Senthil M, Constable PA. Visual acuity and reading print size requirements in children with vision impairment. *Clin Exp Optom*. 2023;1-7. doi:10.1080/08164622.2023.2279190

Loh L, Prem-Senthil M, Constable PA. A systematic review of the impact of childhood vision impairment on reading and literacy in education. *J Optom*. 2024;17(2):100495. doi:10.1016/j.optom.2023.100495

Loh L, Gatsios A, Prem-Senthil M, *et al*. Cone dystrophy, childhood vision impairment and education: are clinical measures of visual function adequate to support a child through education? *Clin Exp Optom.* 2022*;*105(7):774-777. doi:10.1080/08164622.2021.1971044

Constable PA, **Loh L**, Prem-Senthil M, *et al*. Visual search and childhood vision impairment: A GAMLSS-oriented multiverse analysis approach. *Atten Percept Psychophys.* 2023*;*85(4):968-977. doi:10.3758/s13414-023-02670-z

Conference Oral Presentations

Loh L. Functional Vision Assessments: Providing Clarity for teachers and educators. South Pacific Educators of Vision Impairment (SPEVI); Adelaide, South Australia. 12^{th}-15^{th} January 2020.

Loh L, M Prem-Sentil, Constable P.A. Visual Acuity and Reading Ability – Time for Change in the Classification of Childhood Vision Impairment. 77^{th} Orthoptics Australia Virtual Annual Conference: Online: 26^{th} - 27^{th} February 2022.

Loh L. A functional framework for the assessment and support of a student with a vision impairment through education. VISCON, Sydney, New South Wales, Australia. 19^{th}-20^{th} October 2023.

Conference Poster Presentations

Flinders University DocFest 2020: Two-minute thesis.

Best poster presentation – people’s choice award.

Loh L, M Prem-Sentil, Constable PA. Visual Acuity and Reading Ability – Time for Change in the Classification of Childhood Vision Impairment. Royal Australian and New Zealand College of Ophthalmologists Annual Congress. Online: 26th February to 1st March 2022.

Australian Vision Research Recommended Abstract.

Other Presentations

Additional presentations, workshops and teaching are included in Appendix.

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Last but certainly not least, to all the teachers and students at SASSVI. Thank you for everything you have taught me over the last few years. All of this would have been impossible without you.

This thesis is dedicated to my dad, who taught me how to be a good person, a good parent, and also taught me how much fun it was to be around children.

Figures

Tables

Abbreviations

ABCA4: ATP-binding cassette sub-family A member 4

CASP: Critical Appraisal Skills Program

cd: candela

COVID19: Coronavirus Disease 2019

CPS: Critical Print Size

CI: Confidence Interval

CVI: Cerebral Vision Impairment

D: Dioptre

DA: Dark Adapted

db: Decibel

ECC: Expanded Core Curriculum

ERG: Electroretinogram

ERIC: Education Resources Information Centre

ETDRS: Early Treatment of Diabetic Retinopathy Study

F: Female

FAF: Fundus Autofluorescence

FrACT: Friedburg Acuity Test

GAMLSS: Generalised Additive Models for Location Scale and Shape

ISCEV: International Society for Clinical Electrophysiology of Vision

LA: Light Adapted

LE: Left Eye

LGN: Lateral Geniculate Nucleus

LHON: Leber's Hereditary Optic Neuropathy

M: Male

MAR: Minimum Angle of Resolution

MCAT: Modified Cone Adaptation Test

MNREAD: Minnesota Low Vision Reading Chart

MRS: Maximum Reading Speed

n: Number of Participants

N/A: Not Applicable

NAPLAN: The National Assessment Program – Literacy and Numeracy

NARA: Neale Analysis of Reading Ability

NLP: No Light Perception

NP: Normal Polarity

NPC: Near Point of Convergence

NRS: Number Reading Speed

OCA: Oculocutaneous Albinism

ON: Optic Nerve

ONG: Optic Nerve Glioma

ONH: Optic Nerve Hypoplasia

PEST: Parameter Estimation by Sequential Testing

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

QOL: Quality of Life

RB1: Retinoblastoma-1

RE: Right Eye

RGC: Retinal Ganglion Cell

ROP: Retinopathy of Prematurity

RP: Reverse Polarity

RPE65: Retinal Pigment Epithelium-65

RR: Reading Reserve

RT: Reaction Time

SASSVI: South Australian School for Vision Impairment

SD: Standard Deviation

SEM: Standard Error of the Mean

Td: Troland

TVAS: Test of Visual Analysis Skills

UNESCO: United Nations Educational, Scientific and Cultural Organization

UNICEF: United Nations Children’s Fund

V1: Primary Visual Cortex

VA: Visual Acuity

VI: Vision Impairment

WHO: World Health Organization

WPM: Words Per Minute

Thesis and Personal Introduction

In April 2015, I accepted a position at Guide Dogs SA.NT as a low vision specialist. As a trained Optometrist I had undergone training to assess and support an individual with low vision.

A significant part of this new role with Guide Dogs SA.NT was the functional vision assessment of children with a vision impairment who were supported by The South Australian School and Services for Vision Impaired (SASSVI). However, the reality of what I had undertaken became apparent immediately. Vision impairment is a complex entity. As a trained clinician, it was a steep learning curve to understand the variability in function that each vision impairment produced. Optometrists are taught that visual acuity is 'the' measure of the eyes resolution capacity and is determined by overall ocular health. However, it was apparent that visual acuity did not inform me, or the child's teachers, about how visual acuity related to functional vision or how visual acuity could answer the main question often asked - "So what can they do with the vision they have?"

Funding and support for children with a vision impairment was also confounding. Historically and for no other reason than visual acuity is easy to measure and categorise vision impairment, it was used to determine the level of support everyone received regardless of their unique visual needs. It didn't take long to understand what many support teachers already knew, that visual acuity did not represent the functional vision of the individual, with some students receiving higher levels of support than required, whilst others were left without adequate support and struggled with educational tasks.

This thesis was developed from these personal experiences, working with children with a vision impairment and their teachers in the classroom, which revealed the need to re-evaluate how best to determine the actual needs of a child with a vision impairment and the most appropriate level of support that they required. If a clinical functional vision framework could be developed then this would, not only would it improve support for these students, but it would also allow for support to be focussed where it was most needed, and to the students who were most in need.

CHAPTER 1 : INTRODUCTION

The World Health Organization (WHO) emphasises the importance of good vision in children for the development of social and motor skills, as well as for accessing educational resources, thereby maximising their academic capabilities (World Health Organization (WHO), 2019). However, children with a vision impairment (VI) often face challenges in reaching these milestones through an inability to effectively access classroom materials, affecting their ability to reach their full potential. This thesis aims to explore whether interventions to address difficulties accessing learning material can improve educational outcomes for children with a VI through a functional assessment of their vision.

1.1 Vision Assessment

Visual acuity (VA) is the measure of the eye's resolution ability when optimally corrected for any refractive error and is traditionally measured using by asking the individual to read letters on chart, that vary in size, at 6 meters. The '6' as the numerator denotes the viewing distance (in meters) and the denominator refers to the size of the letter and the Minimum Angle of Resolution (MAR), which is the smallest angular separation of two points that the observer can distinguish (Kniestedt and Stamper, 2003). The 6/6 letters on a VA chart subtend 5 minutes of arc, and each limb of the letter subtends 1 minute of arc. A VA of 6/6 indicates that the observer can resolve a letter subtending 5 minutes of arc or resolve two points separated by an angle of 1 arc minute at 6 metres as depicted in **Figure 1.1**. If the observer has a VA of 6/12, their MAR is 2 minutes of arc at 6 metres. The VA can be written as a fraction i.e., 6/6, or a decimal i.e., 1.0, or logMAR (log1.0) =

0. See **Table 1.1** for VA conversions. In this thesis measures of VA are denoted in logMAR units unless otherwise specified.

Figure 1.1: Visual Acuity

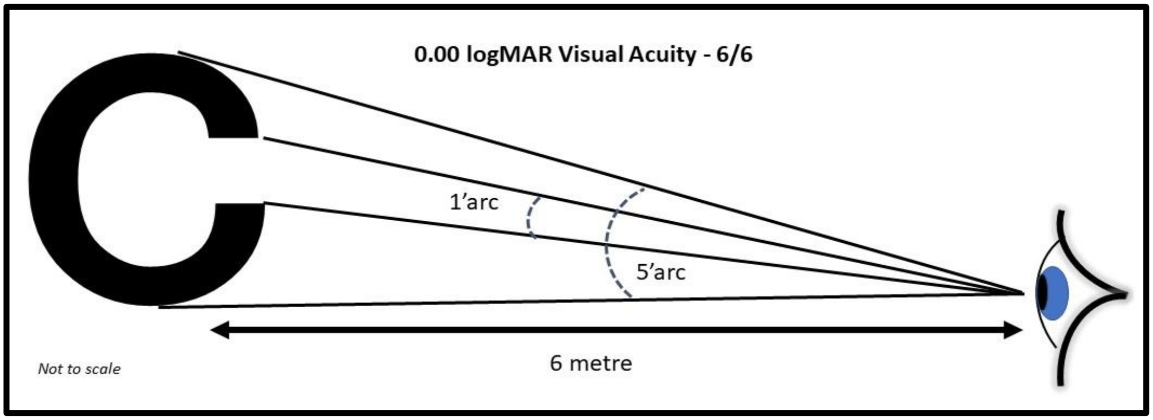


Figure 1.1. Schematic representation of an eye with 0.00 logMAR (6/6) visual acuity, viewing a Landolt C, which subtends 5 arc minutes with a minimum angle of resolution (MAR) of 1 arc minute (the space in the 'C'). The angle of resolution refers to the smallest angular separation between two points that can be distinguished by the visual system. It is a measure of the spatial resolution of the eye. The smaller the minimum angle of resolution, the higher the visual acuity.

Table 1.1: Visual acuity conversions

Snellen Fraction	Decimal	MAR	logMAR
6/6	1.00	1.0	0.0
6/12	0.50	2.0	0.3
6/18	0.33	3.2	0.5
6/60	0.10	10.0	1.0

Table 1.1. Conversions of visual acuity in Snellen fraction, decimal, minimum angle of resolution (MAR) and logMAR. The Snellen Fraction refers to the viewing distance (in meters) divided by the letter size that subtends 5 minutes of arc when viewed at a distance denoted by the denominator (6, 12...60). The decimal is the decimal fraction.

VA is limited in part by physiological factors determined by cone photoreceptor spacing at the fovea. For the optimum resolution limits to be obtained other additional factors must also be present. Good optics is required for effective passage of light though ocular structures, foveal fixation ensures that the image is stable, and retinal photoreceptors and post receptor neurons need to have normally functioning neural pathways to the primary visual cortex (V1) and higher cortical regions for visual perception (Westheimer, 1965).

Visual perception is organised into specialised cortical areas with the primary visual cortex (V1) also referred to as the striate cortex or Brodmann's area 17, concerned with the initial processing of object features such as orientation, motion, wavelength, and depth (Hubel and Wiesel, 1968; Zeki, 1976). From V1, further processing occurs in extra striate regions that are more specialised for colour perception (V4) and motion (V5). Broadly, visual information is processed by two streams namely the dorsal or 'where' pathway and the ventral or 'what' pathway that specifically processes information concerning an object's location and motion (where) or the object's identity (what). There are feedforward and feedback mechanisms that contribute to an object's salience between V1 and the higher extrastriate regions (Bullier, 2023; Huff *et al*., 2023; Takemura and Rosa, 2021; 2022).

VA is dependent on V1 and the ability of cells within V1 to determine orientation, length and gaps or spaces between lines. This ability will determine the MAR of an observer and can be best measured using a grating pattern. The stripes of a grating (black and white bars) can be varied to determine the MAR and do not require a subjective response of ‘naming a letter’ and can be further manipulated to vary orientation and contrast systematically which is advantageous in non-verbal paediatric individuals with a VI that may have a very low VA (Hopkins *et al*., 2017). Gratings provide a more psychophysical measure of VA based on discrimination of the spacing and contrast of the lines. Grating acuity or spatial acuity is the ability of the visual system to distinguish between closely spaced lines or gratings and is a measure of the smallest details that the observer can perceive in a visual stimulus. Grating acuity is tested typically using sinusoidal gratings, which are patterns of alternating light and dark bars shown in **Figure 1.2**. The finest grating that an observer can perceive at a specific distance is used as a measure of their grating acuity. Grating acuity is usually expressed in cycles per degree, which indicates how many cycles of the grating can fit within a single degree of visual angle. They have the advantage of being able to probe the early stages of visual processing involving spatial acuity, orientation and contrast that are features processed in V1 (Duong and Freeman, 2007). Letters or shapes in contrast require higher cortical areas involving form/shape and object recognition such as V4 (Pasupathy *et al*., 2020).

Figure 1.2: Grating Acuity Test Chart

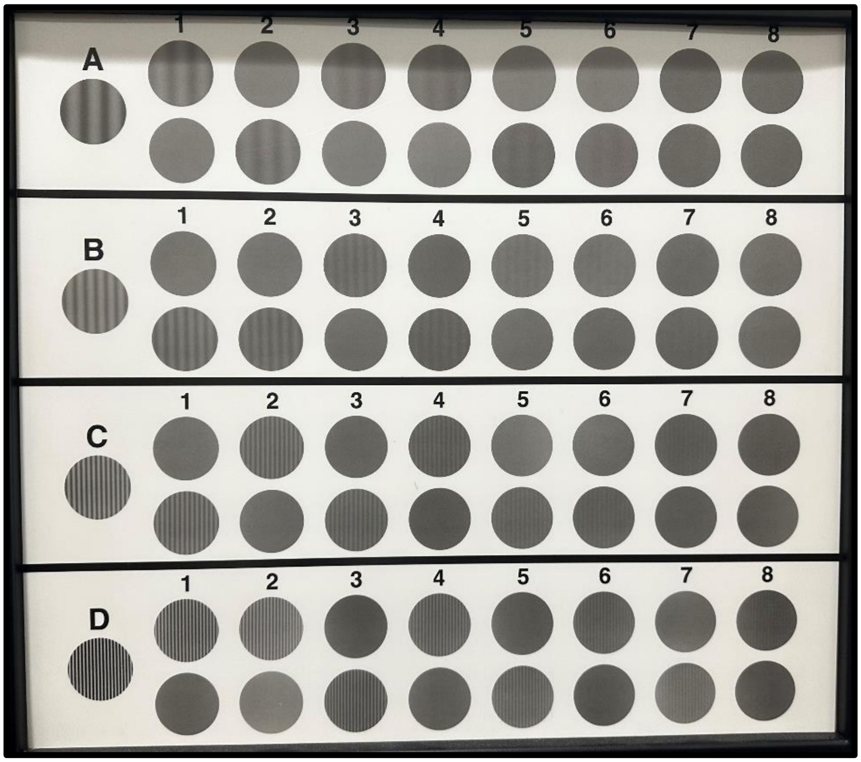


Figure 1.2. Grating acuity features a series of black and white stripes (gratings) with varying spatial frequencies (A-D) which are measured in cycles per degree. Higher spatial frequencies (finer gratings) are more difficult to resolve and are used to test higher levels of acuity. The contrast and orientation (1-8) of the gratings may be further varied to obtain a more accurate measure of visual resolution.

Development of Visual Acuity Test Charts

Commonly, VA is measured through the identification of letters on a test chart. To do this, the observer is required to identify features of the letter, such as orientation, edges and length, that are integrated into the perception of a 'letter' which the observer must then process and name either verbally or through matching with a card. One of the earliest mentions of VA measurement dates back to the early 1600's where the ability to resolve double stars and see mustard seeds were mentioned (Colenbrander, 2009). In 1843, the physician, Henrich Kuechler, advocated for a standardised way of measuring vision and developed a chart with three different words per line that progressively decreased in size and is shown in **Figure 1.3**.

Figure 1.3: Kuechler Vision Chart

Figure 1.3. The 1843 Kuechler vision chart which was designed with three different words per line that progressively decreased in size with each of the twelve lines. Figure from Colenbrander, (2009).

The Snellen chart, which was developed a decade later, began its inception in 1861 at an ophthalmology conference in Heidelberg. Franciscus Cornelis Donders proposed a formula which enabled the calculation of the "sharpness of vision" however, it was his colleague, Herman Snellen, who developed a tool to measure vision based on the formula of the ratio of letter size to viewing distance. So that a letter at 6 meters subtended an angle of 5 minutes of arc and the letter size when viewed at 12 meters also subtended 5 minutes of arc. A contemporary internally illuminated Snellen chart is shown in **Figure 1.4**.

Figure 1.4: Snellen Vision Chart

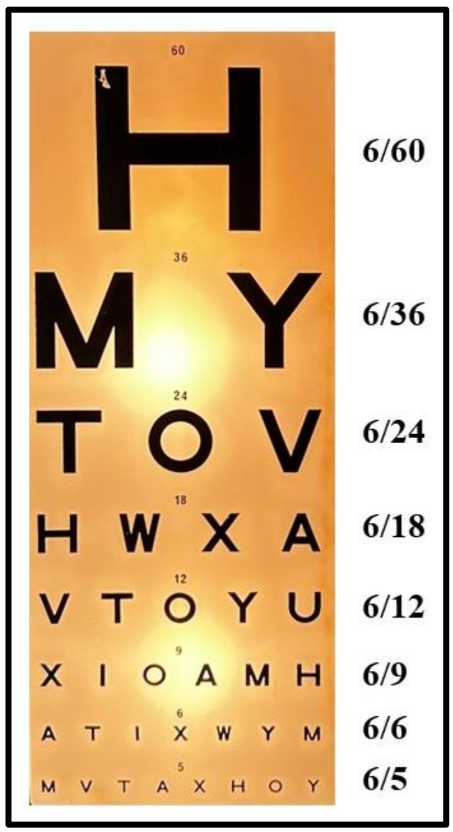


Figure 1.4: The Snellen acuity chart illuminated from the back, exhibiting inconsistent lighting across its surface. The top line contains one letter 'the 6/60 letter' that subtends 5 minutes of arc at 60m with each successive line getting smaller, to the smallest letter size that subtends 5 minutes of arc at 5m. The number of letters increase on each line by one, resulting in the bottom 6/5 line containing 8 letters.

The Snellen letter chart has several limitations though. Firstly, it was never standardised, so different manufacturers produced charts with varying space between lines and letters, which resulted in errors when measuring VA at different distances for individuals with lower vision. VA based on a Snellen chart is also scored as a line assignment method with VA recorded as the correct line of letters read. Therefore, due to the varying numbers of letters per line, missing one letter on a higher acuity line (with 7 or 8 letters) has less impact than missing a letter on a lower acuity line (with less than 4 letters). Additionally, due to the lack of standardisation, any letters can be used on a Snellen chart, and as letters have varying legibility's, for example C, D, E and O are easier to read than A, J and L, this makes the test-retest variability high with Snellen charts and therefore an unreliable measure for research studies (Bailey and Lovie, 2013; Kaiser, 2009; 2015; Lovie-Kitchin, 1988).

LogMAR and ETDRS Acuity Charts

Recognising that a more accurate and reliable method of testing VA was required, the Bailey-Lovie distance VA (logMAR) charts were developed (Bailey and Lovie, 1976) and are also known as the Early Treatment of Diabetic Retinopathy Study (ETDRS) charts (Ferris *et al.*, 1982) as shown in **Figure 1.5**. The logMAR charts have been shown to be a more accurate and reliable measure for VA with measures twice as repeatable as those from Snellen charts (Lovie-Kitchin, 1988; 2015). This improved reliability was achieved through several features- including:

1) Equal number of letters (five) per row.
2) Each row of letters and the separation between letters and rows is identical.
3) Each line contains letters with similar or equal legibility.

4) The letter size on each row follows a reducing logarithmic progression of sizes with letters becoming smaller by 0.1 log units per line.

These features allow the logMAR chart to be used accurately at different testing distances making them suitable for studies in participants with low VA (Becker *et al.*, 2007).

0.00 logMAR, 6/6 (metric notation) or 20/20 (imperial notation) are familiar numbers and are considered as a normal level of VA (Pitts, 1982) despite most individuals being able to resolve letters smaller than this level (Ferris *et al.*, 1982).

Figure 1.5: logMAR Vision Chart

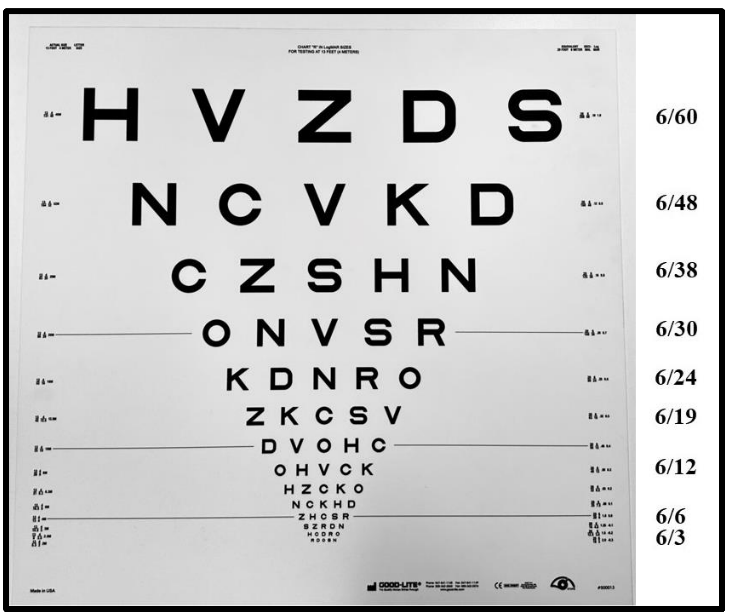


Figure 1.5. A logMAR charts with 5 letters each line of simar legibility. The spaces between letters and lines are standardised and with each row of letters progressively becoming smaller by 0.1 log units per line. For most observers the 0 logMAR line is taken as 'normal' visual acuity but most observers can resolve letters below this line.

Within a clinical environment, VA is heavily relied upon as an outcome measure, both to determine normality, but also to monitor and record changes due to pathology or following medical or surgical interventions. The fractions 6/6 and 20/20 are widely recognised as “normal” vision or vision to be attained following treatment with vision < 6/6 considered to be reduced.

To achieve optimum “normal” VA all anatomical, optical, and physiological elements of the visual system must be functional. The resultant measure of VA can therefore be affected by many factors that may interfere with normal visual function and result in reduced VA. For example, the quality of ocular media and integrity of the visual pathways that all change with age can contribute to a decline in VA observed with age (Greene and Madden, 1987; Pitts, 1982).

1.1.1 Refractive Errors

Uncorrected myopia and/or astigmatism may present with reduced vision (Atchison *et al*., 1979; Kleinstein *et al*., 2021). Uncorrected hyperopia in children rarely manifests as reduced vision but can cause asthenopia (visual fatigue) or an accommodative eso-deviation (Lembo *et al*., 2019). This is because, in younger populations, the amplitude of accommodation is greatest, and so young individuals can use their accommodative reserve to compensate for a hyperopic refractive error and may only report some discomfort with near tasks when accommodative demands increase (Chen and Borsting, 2023).

In ametropia (uncorrected refractive error) a reduction in pupil size results in an increase in VA. This can be demonstrated with the use of a pinhole test, where VA increases in uncorrected refractive error due to a reduction in the blur circle on the retina as represented schematically in **Figure 1.6** with a similar effect observed with pupil size in emmetropia (Atchison *et al*., 1979).

Figure 1.6: The effect of a pinhole on the retinal blur circle in myopia

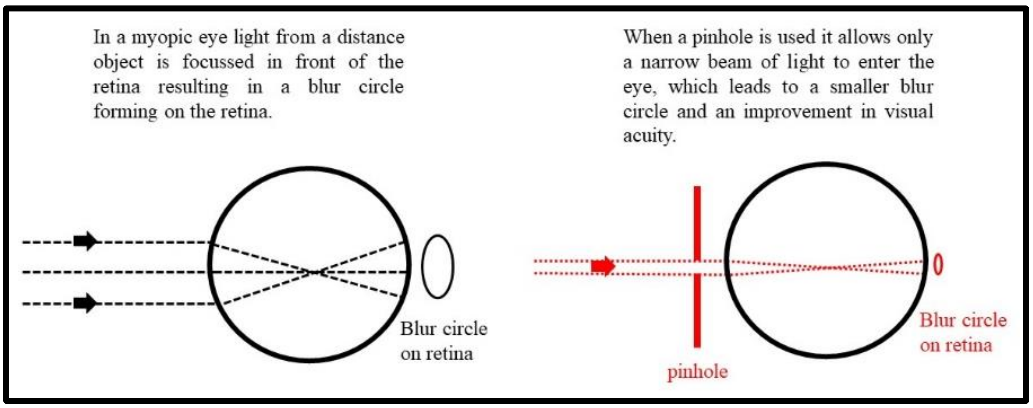


Figure 1.6. A myopic eye, where light is focussed in front of the retina producing a large blur circle on the retina (left) and with a pinhole (right) where a narrow beam of light produces a smaller blur circle on the retina in the same eye thereby improving visual acuity.

1.1.2 Ocular Media

An essential aspect of vision is the clear transmission and refraction of light through the ocular structures, including the cornea, lens, and vitreous humour to the retina.

Cornea: The cornea is the transparent, dome-shaped anterior surface of the eye. It is the eye's primary refractive element and is responsible for about two thirds of the eye's total refractive power due the change in refractive index from air to the tear film and anterior corneal surface

(Navarro, 2009). Conditions affecting corneal transparency, such as inflammation with secondary oedema and scarring, dystrophies or ectasia can degrade the passage of light, leading to reduced VA, contrast sensitivity and may be a source of glare through the scattering of light at the first optical interface (Miller and Sanghvi, 1990).

Aqueous Humour: The aqueous humour is the clear fluid that fills the anterior and posterior chambers of the eye, situated between the endothelial layer of the cornea and the anterior pole of the lens, and maintains the intraocular pressure, provides nutrients to the avascular lens and cornea and removes metabolic waste (Civan and Macknight, 2004). When there is acute anterior chamber inflammation, there is a breakdown of the blood-aqueous barrier resulting in cells and protein leaking into the aqueous that cause glare and reduced VA (American Academy Ophthalmology, 1990).

Crystalline Lens: the lens of the eye is located behind the iris and provides the remaining one third of the refractive power of the eye (Navarro, 2009), which is 25.5 ± 3.0 Dioptres (D) in humans (Iribarren *et al*., 2012). The lens is flexible, and its ability to change shape allows the lens to change its power from approximately 20-33D (Navarro, 2009), which is essential for the ability of the eye to focus on objects at varying distances. Clouding of the lens (cataract), results in light scatter which reduces VA, contrast sensitivity, and causes glare (Elliott *et al*., 1989; Ruan *et al*., 2020).

Vitreous Humour: This is a clear, gel-like substance that fills the space between the lens and the retina. It helps maintain the eye's shape and allows unhindered transmission of light to pass through to the retinal photoreceptors (Holekamp, 2010). Opacities such as vitreous floaters within the vitreous humour can obstruct passage of light (Milston *et al*., 2016). Floaters (myodesopsias), generally have minimal impact on vision, but they can cause a reduction in contrast sensitivity (Ankamah *et al*., 2022), glare, and reduced quality of life (Milston *et al*., 2016).

Any condition that affects the transparency of the cornea, lens, or vitreous humour can impact visual function through light scatter or reduced transmission and a loss of contrast, thereby reducing VA and/or contrast sensitivity which may affect functional tasks such as reading and driving at night (Liu *et al*., 2017; Miller and Sanghvi, 1990; Milston *et al*., 2016). The main cause of VI in older individuals may be caused by a cataract as part of the normal ageing process, which can cause glare and can impact visual quality in bright light conditions or when viewing an illuminated source, such as an electronic display screen (Liu *et al*., 2017).

1.1.3 Retina

The retina is the neurosensory tissue that transduces light into electrical signals that are conveyed to the lateral geniculate nucleus (LGN) via the optic nerve. Light is focussed on a specialised region of the retina, called the fovea, which is the region of the retina with maximum VA due to the tightly packed cone photoreceptors (Bringmann *et al*., 2018; Song *et al*., 2011). Spatial (Beck and Halloran, 1985) and word acuity (Abdelnour and Kalloniatis, 2001) decreases in the peripheral retina as a function of cone density that declines with rod photoreceptors being more numerous as retinal eccentricity increases from the fovea (Dabir *et al*., 2014). The concentration of cone receptors and ganglion cells (Curcio and Allen, 1990) decrease with eccentricity which contributes to a decline in VA in the retinal periphery. **Figure 1.7** depicts the exponential decline in acuity with retinal eccentricity (Weiskrantz and Cowey, 1967).

Figure 1.7: Visual acuity decline with retinal eccentricity

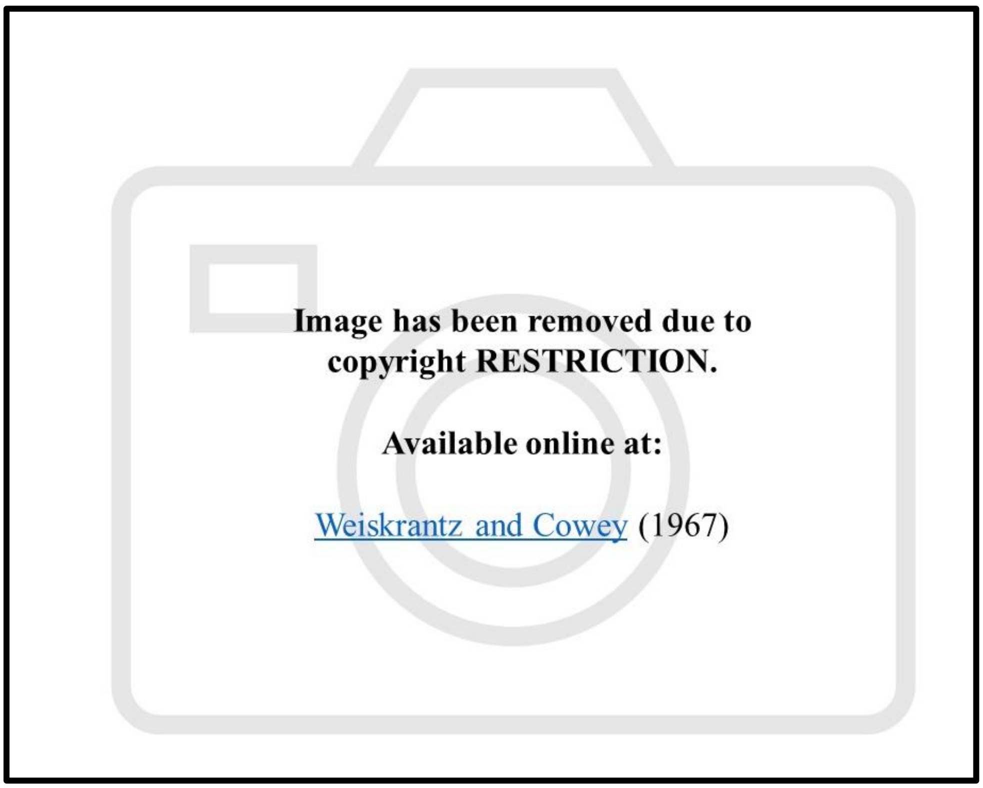


Figure 1.7. The decline in visual acuity with retinal eccentricity in human (solid line). Circles and squares indicate relative acuity in monkey retina and visual cortex respectively following lesions. Figure from Weiskrantz and Cowey (1967).

The visual system can adapt to a large range of luminance (10 log units) with the cone photoreceptors mediating photopic, or 'daytime' vision, and rod photoreceptors being adapted for low levels of luminance in scotopic, or ‘nighttime’ vision (Perlman and Normann, 1988). Cones are specialised photoreceptor cells that are responsible for colour vision and VA. They are sensitive to different wavelengths of light, allowing us to perceive a wide spectrum of colours (Mustafi *et al.*, 2009). In contrast to cones, the rod photoreceptors have greater sensitivity to photons and function optimally under scotopic conditions but do not contribute to the sense of colour, only luminance, and outnumber cones by a ratio of 20:1 in the human retina (Kawamura and Tachibanaki, 2008). Due to the anatomical and physiological differences in rod and cone photoreceptors, the spatial arrangement of the cones determines the eyes resolution limits at the retinal level (Rossi and Roorda, 2010).

Broadly, human visual performance will vary depending on the state of retinal adaption and the luminance, based on the contributions of the cone and rod driven pathways. Luminance levels are commonly delineated into three bands: photopic, mesopic, and scotopic and are described in **Figure 1.8**.

Photopic Vision: During conditions of high luminance (above 3.0 cd/m^2), the visual system operates within the photopic region, where cone photoreceptors dominate. In this region, VA is at its maximal level owing to cone driven pathways that also enable colour vision.

Mesopic Vision: As luminance decreases to intermediate levels (0.01-3.0 cd/m^2), corresponding to twilight conditions, the visual system enters the mesopic region. Here, both cone and rod photoreceptors contribute to vision and there is a transition between pure cone to pure rod pathways in the retina that can affect different aspects of visual function (Stockman and Sharpe, 2006).

Scotopic Vision: In conditions of low luminance (below 0.01 cd/m^2), visual performance is driven by the rod photoreceptors. Rods are more sensitive to low levels of light, but the rod pathways of the retina lack the spatial resolution of cone pathways. Consequently, there is a marked decline of up to 10x in vernier acuity under scotopic conditions (Freundlieb *et al*., 2020).

Figure 1.8: Photopic, Mesopic and Scotopic Visual Ranges

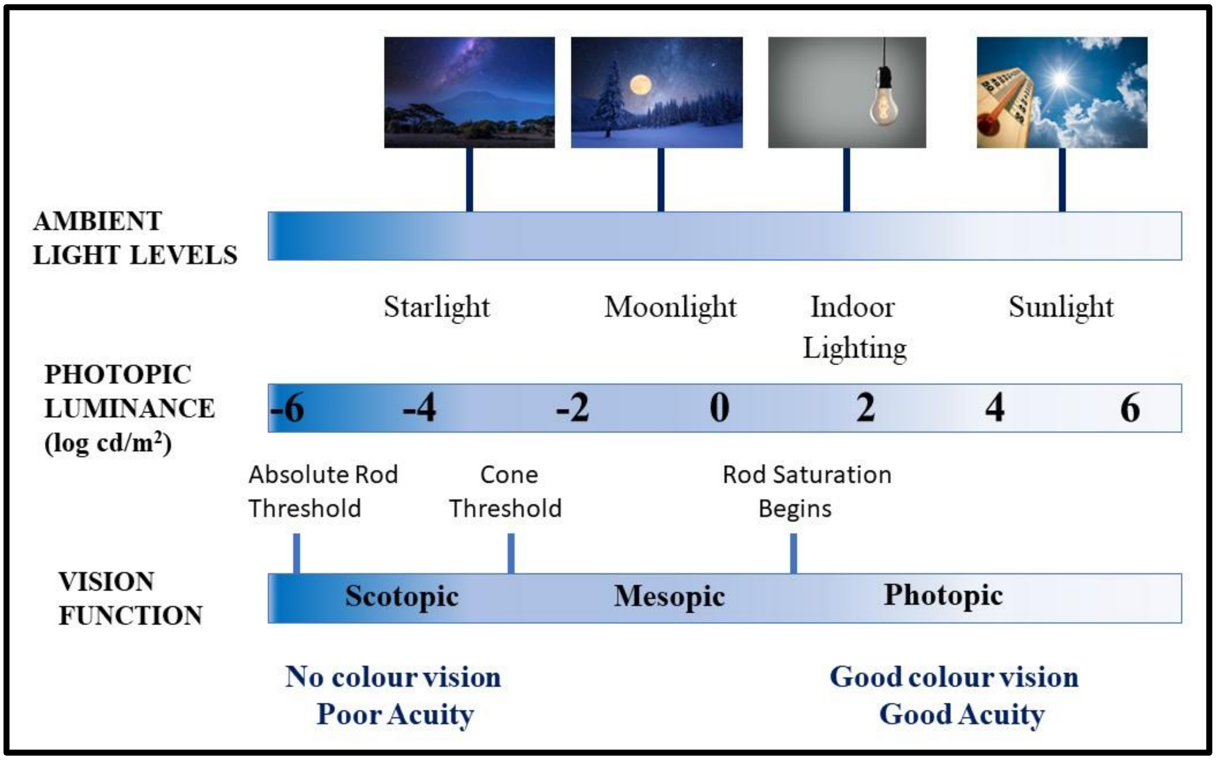


Figure 1.8. The three broad regions of visual function based on luminance. Scotopic, mesopic and photopic, and typical ambient light levels, photopic luminance (log cd/m^2) and visual function.

Current vision requirements are based on photopic (daytime) vision, and therefore mediated by the retinal cone pathways.

As illumination levels reduce to mesopic level, vision is transitioned from cone to rod mediated. While rods are primarily responsible for low-light vision, cones also play a role, especially during the initial stages of transitioning from bright to dark environments. Cones have a faster response time but are less sensitive to light compared to rods. During the initial stages of dark adaptation, vision is limited, and details are not seen as clearly.

The processes of dark adaptation and light adaptation are examples of the adaptive capabilities of the human visual system to changes in luminance during day and night. The ability to adapt efficiently is an important factor in those with a VI who may have disruption to the rod or cone pathways that may challenge these individuals when moving from an outdoor high luminance environment into the classroom (Hood and Finkelstein, 1986). Equally important is moving from a dim environment to a bright environment where the cone pathways may take longer to adapt and the individual with a VI may experience glare or photophobia during the period of light adaptation and require tinted optical corrections (Rosenblum *et al*., 2000).

The wide range of luminance levels that the visual system can adapt to optimise performance is complex and dynamic (Stockman and Sharpe, 2006). Therefore, when the assessment of visual function for an individual with a VI is undertaken, it is important to consider the limitations they may have based on their retinal function and the range of luminance levels that they transition into and out of during their schooling.

The process of dark adaptation is typically impaired and may be delayed significantly in rod dystrophies such as retinitis pigmentosa (Alexander and Frishman, 1984), which was a common cause of VI in the study population reported in this thesis. In rods, rhodopsin is the light sensitive photopigment that is composed of a protein (opsin) and the light sensitive 11-*cis*-retinal (Downer and Englander, 1975). Following light absorption by 11-*cis*-retinal the rod opsin undergoes a conformational change to initiate phototransduction of light to an electrical signal that is transmitted to the second order neurons (bipolar and horizontal cells) of the retina. For the rods, the regeneration for the visual pigment takes time and contributes to the slow time (~20 minutes) for the human retina to be fully dark adapted and most sensitive to photon capture (Bloomfield and Dacheux, 2001; Lamb and Pugh, 2004; Wald and Brown, 1958). This sensitivity allows a sense of our surroundings even when there is very little ambient light available.

The relationship between VA and retinal illuminance is shown in **Figure 1.9**, that illustrates maximal VA under photopic conditions, with a gradual decrease in VA through mesopic levels to scotopic conditions (Shlaer *et al*., 1942). Most individuals are aware of this having been in circumstances where they are unable to read in dimly lit environments without the assistance of extra light to increase contrast, for example when reading a menu in a restaurant or on food packaging.

Figure 1.9: Human resolution acuity as a function of retinal illuminance

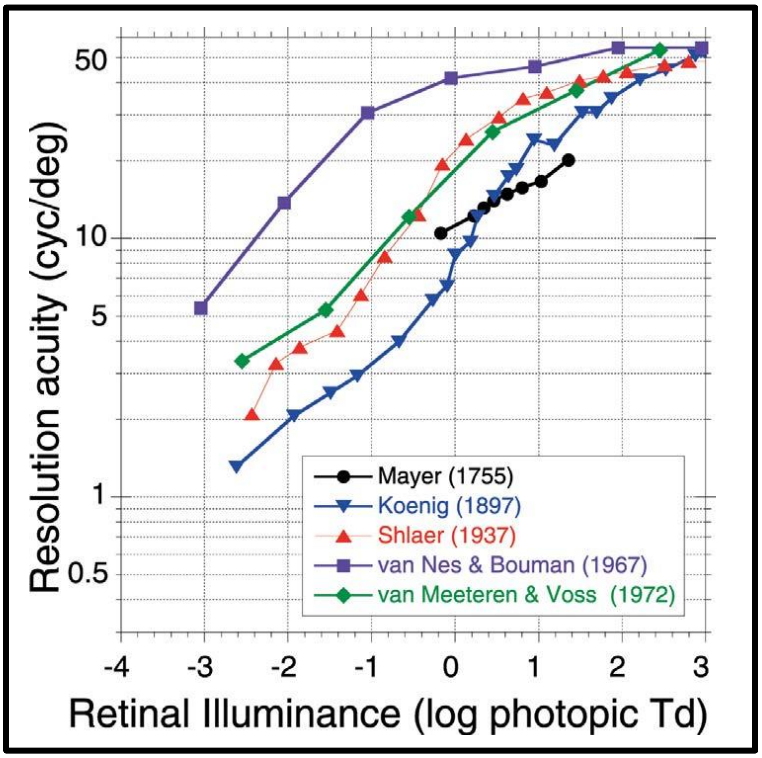


Figure 1.9. Relationships between resolution acuity (cycles/degree) and log retinal illuminance (photopic Troland (Td) reported in previous studies. Low retinal illuminance represents the rod response and lower VA under scotopic conditions. Higher retinal illuminance (>0 log photopic Td) represents the cone dominated contribution to VA that improves with increasing retinal illumination. Figure from Wilkinson *et al*., (2020). Reproduced under a CC-BY-NC-ND licence.

Retinal Dystrophies

Retinal dystrophies are a complex and heterogeneous collection of disorders, with a wide range of defects at the molecular and cellular level affecting primarily rod or cone pathways in the retina or the macular region (Verbakel *et al*., 2018). Examples of retinal dystrophies, that may be inherited as autosomal dominant, recessive or sex-linked, include Retinitis Pigmentosa, Leber's Congenital Amaurosis (autosomal dominant or recessive), Stargardt disease (autosomal recessive), and cone-rod dystrophies (sex-linked, autosomal dominant and recessive) (Manley *et al*., 2023). The type of dystrophy determines the impact it has upon visual function. Rod dystrophies typically result in a loss of function under scotopic conditions and peripheral visual field loss, whereas cone dystrophies have a more significant effect on VA, colour discrimination and can be susceptible to photophobia (Ito *et al*., 2022; Nguyen *et al*., 2023).

Children will typically present with nystagmus and experience a gradual loss of visual function depending upon the dystrophy. X-linked conditions tend to be most severe resulting in earlier loss of function, for example in Retinitis Pigmentosa. Leber’s can also affect VA markedly in early childhood (Murro *et al*., 2023).

Figure 1.10: Cone Dystrophy

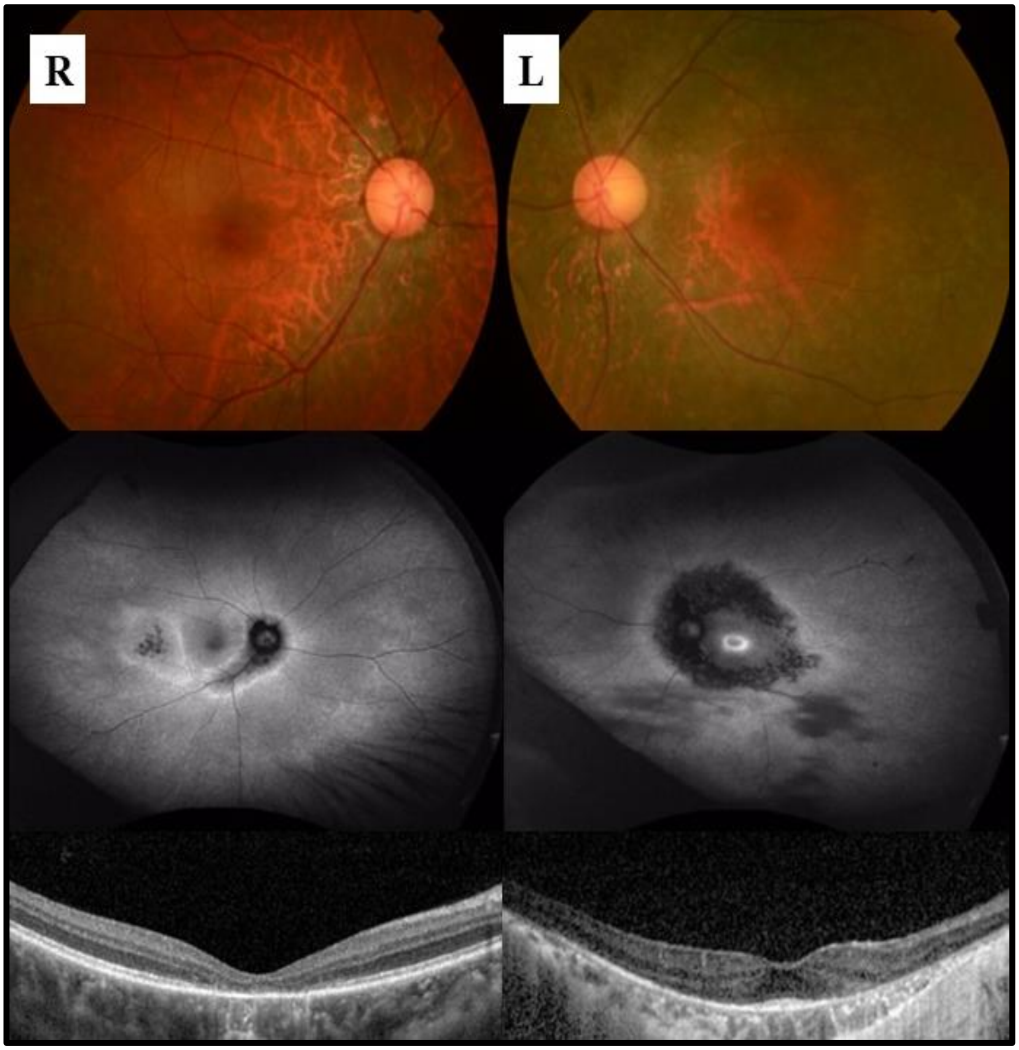


Figure 1.10. Fundus photographs (top) of a patient with a cone dystrophy. Wide field Fundus autofluorescence images (below) showing mid peripheral hypofluorescence L>R with the left eye at a more progressive stage with hyperfluorescent ring centred at the fovea. Lower figures show the optical coherence tomography b-scans of the macula with outer retinal loss of photoreceptors L>R with loss of the ellipsoid zone. Images courtesy of Prof Ian Yeo, Singapore National Eye Centre.

The current treatment tor retinal dystrophies are limited with gene therapy available for Leber's (retinal pigment epithethelium-65, *RPE65*) (Chiu *et al*., 2021) and Stargardt disease (Adenosine tri-phosphate Binding Cassette, *ABCA4*) (Sun *et al*., 2022). Otherwise, it is left to low vision services to provide support for students within mainstream classrooms who may be impacted functionally, depending on the type of retinal dystrophy, by a loss of reading ability, colour vision deficits, photophobia, and reduced visual search ability. All these functional deficits can result in difficulties accessing classroom materials to the same ability as their normally sighted age equivalent peers.

Retinal disorders can also be the result of tumours, including retinoblastoma, a malignant tumour of the retina and the most common childhood neoplasia caused by mutations in retinoblastoma-1 (*RB1)* (Fabian and Sagoo, 2018). Retinoblastoma may result in enucleation or VI following treatment with brachytherapy (Shields *et al*., 1993).

1.1.4 Visual Pathway

The visual pathway is the neural network responsible for transmitting visual information from the retina to the brain for processing that is shown schematically in **Figure 1.11**. The main components of the visual pathway comprise the retina and optic nerve (cranial nerve II) that contains approximately 1.2 million retinal ganglion cell (RGC) axons that synapse at the LGN before neural pathways through the parietal and temporal lobes (forming the optic radiations) to the visual cortex in the occipital lobe where further processing occurs involving orientation, wavelength, depth, and motion (Celesia and DeMarco, 1994). Schematic of the visual pathway

Figure 1.11: Schematic of the Visual Pathway

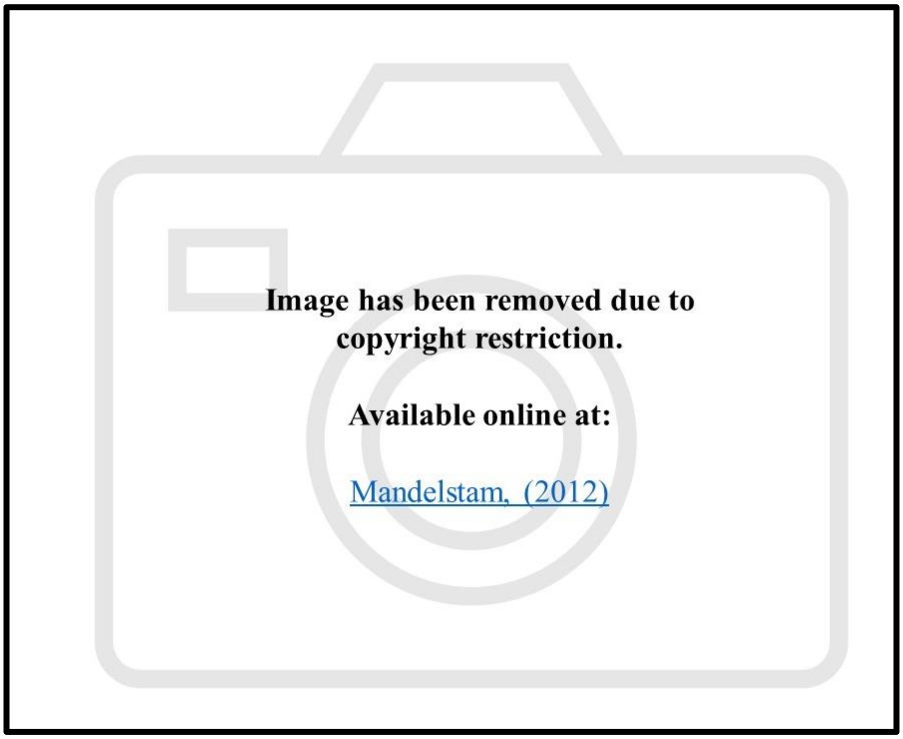


Figure 1.11. Showing the visual pathway as information is relayed from the eyes to the visual cortex. Light enters the eyes through the pupil and is refracted by the main optical elements of the eye - namely the cornea and lens. The nasal fibres cross at the optic chiasm so that each hemifield is represented within the LGN. From the LGN the radiations pass either superiorly through the parietal lobe or inferiorly through the parietal lobe to the primary visual cortex located in the occipital lobe. Figure adapted from Mandelstam, (2012).

Visual Pathway Disorders

Disruption along the visual pathway may result in a loss of vision and/or a visual field defect. Some common childhood conditions such as optic nerve hypoplasia, retinopathy of prematurity (ROP) optic nerve glioma (ONG) and Leber's hereditary optic neuropathy (LHON) affect the optic nerve and transmission of visual information to the LGN.

Optic Nerve Hypoplasia (ONH) is a congenital underdeveloped optic nerve. ONH is one of the leading causes of childhood VI (Gilbert *et al*., 1999) and can be associated with other systemic conditions, such as septo-optic dysplasia which can affect the brain midline and cause pituitary gland abnormalities (Sataite *et al*., 2021). The most common hereditary disorders are autosomal dominant optic neuropathy and maternally inherited Leber's optic neuropathy which typically affects both eyes, and is more prevalent in males, and leads to an acute or gradual loss of vision (Newman and Biousse, 2004). Optic neuritis, while more commonly observed in adults, can occur in children, and is often related to autoimmune conditions or infections. Optic neuritis is an inflammation of the optic nerve and can lead to temporary or permanent vision loss (Pérez-Cambrodí *et al*., 2014). Trauma, including accidents or injuries involving the eye or head can also damage the optic nerve but these are less common, and typically occur in males during childhood (Yu-Wai-Man, 2015). Tumours affecting the connective tissue of the optic nerve, such as ONG, can reduce conduction along the optic nerve leading to vision loss secondary to compression of the RGC axons. ONG accounts for 65% of optic nerve tumours and usually presents within the first decade of life (Ediriwickrema and Miller, 2018). Childhood glaucoma is a heterogenous group of disorders that can result in severe vision loss or blindness due to elevated intra ocular pressure. It can be primary, secondary (including uveitic glaucoma, associated with systemic disease such as neurofibromatosis, or associated with syndromes), or due to trauma or tumours. Primary childhood glaucoma includes congenital glaucoma and juvenile open-angle glaucoma, affecting both eyes in 69% of cases (Karaconju *et al*., 2021). Childhood glaucoma accounts for 5% of blindness globally (WHO, 2020).

1.1.5 Albinism

Oculocutaneous albinism (OCA) is a group of inherited disorders characterised by a lack of pigment in the skin, hair, and eyes. It is caused by mutations in genes involved in the production and distribution of melanin. The condition has eight phenotypes depending on the specific gene affected, with the most common being OCA1 and OCA2. OCA1 is the most prevalent form caused by mutations in tyrosinase (*TYR)* an enzyme involved in melanin production (Lai *et al*., 2018). The clinical presentation of OCA can include white hair and skin, light eyes, decreased VA, nystagmus, and foveal hypoplasia (Grønskov *et al*., 2007; Neveu *et al*., 2022) and misrouting of the RGC axons at the chiasm (Ather *et al.,* 2019). Due to the lack of cutaneous melanin, individuals are at greater risk of melanoma (Ma *et al*., 2023).

In a normally pigmented iris, melanin absorbs the excess light preventing light scatter and glare. In albinism light is not adequately absorbed and can pass through the iris causing transillumination which can be seen on slit lamp examination as shown in **Figure 1.12**. The result of this is photophobia depending on the degree of pigmentation, which leads to visual discomfort and reduced VA, particularly in photopic conditions (Oetting *et al*., 1994).

Figure 1.12: Iris and Iris Transillumination in Ocular Cutaneous Albinism

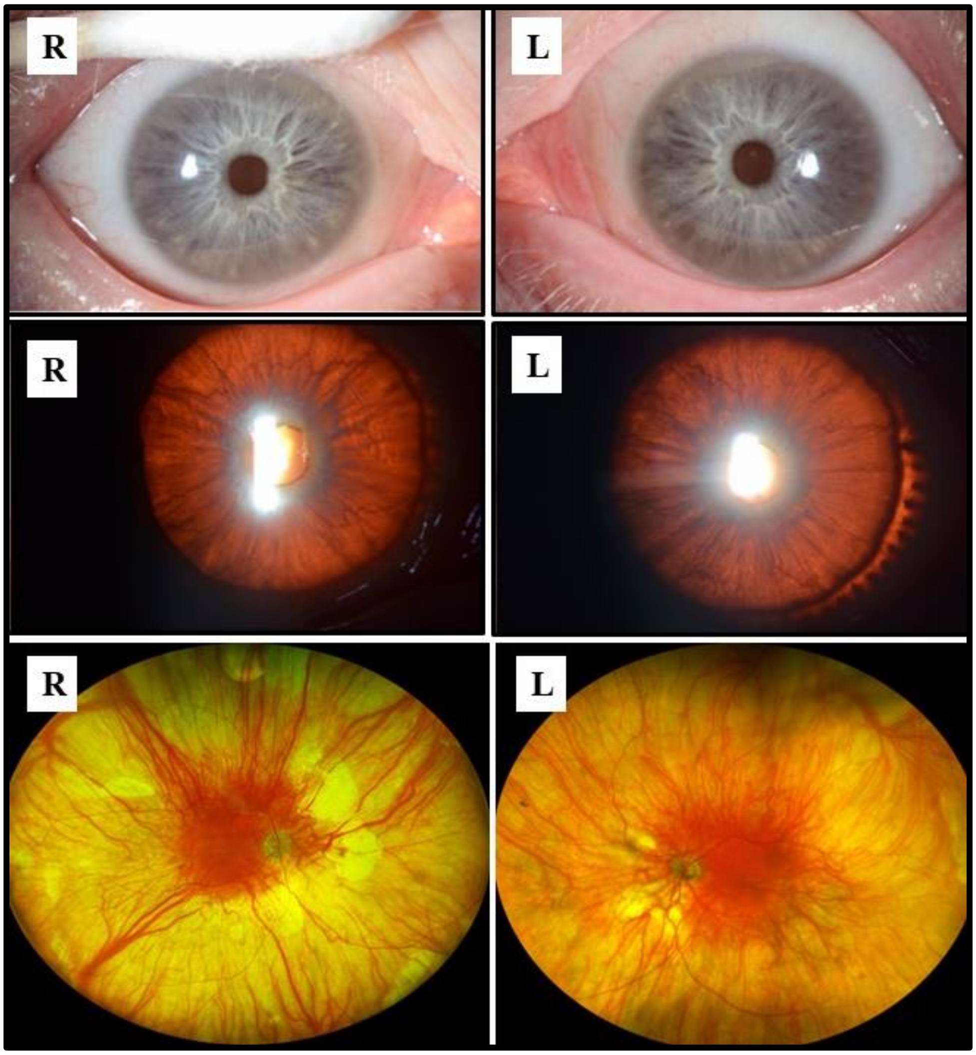


Figure 1.12. Iris photographs of a child with molecular confirmed ocular cutaneous albinism *OCA1* showing reduced pigmentation and transillumination of the iris stroma on slit lamp examination (top two photographs), and fundus photographs showing fundus hypopigmentation and typical foveal hypoplasia (bottom). The lack of melanin in the iris pigment epithelium is a major source of glare and photophobia as well as degrading the retinal image that reduces visual acuity in these individuals. Images courtesy of Professor Ian Yeo, Singapore National Eye Centre.

1.2 Visual Development

VA develops during the first few months of life and the critical period for the development of visual function occurs within the first few years of life (Booth *et al*., 1985). VA is typically measured at adult levels by 11 years of age (Garey, 1984). A VI can result if there is not adequate resolution capability to enable the formation of clear visual input to the visual cortex, or the visual cortex is unable to process the visual information it receives (Hensch, 2005).

The neural components and their connections continue to develop throughout later foetal stages and into the first few weeks after birth, whereas the physical aspects of the eye form during early foetal development. Preterm infants born before 32 weeks of gestation have limited pupillary response to light and thin eyelids, making them less capable of protecting their retinas from light exposure (Graw, 2010). By 36 weeks, infants begin to show improved light-limiting capabilities, although the retinal neural connections are not fully matured. The retinal elements, including the lens, vasculature, vitreous and retina develop with the eye and with growth, rods migrate to the periphery and cones migrate centrally, independent of light exposure (Graven and Browne, 2008; Graw, 2010; Kumar and Reilly, 2020; Lutty and McLeod, 2018; Provis, 2001). The retina originates from a single embryonic layer (neuroectoderm) and differentiates into various specialised cell groups. Rods dominate the visual system until the infant is 2 to 3 months old. Cones, which enable colour vision, develop their neural connections later and become functional a few months after birth as the outer segments develop and lengthen (Graven and Browne, 2008; Graw, 2010). The development of VA occurs rapidly after birth to about 3 years with the development of the fovea and cone outer segment length (Chandna, 1991; Norcia *et al*., 1987).

The RGCs axons form the optic nerve and intersect in an X-shaped pattern at the optic chiasm. These axons then proceed to the LGN and align topographically to relay accurate visual information to the brain's visual cortex so that there is a retinocortical map of vision represented as ocular dominance columns (Holmes, 1945; Hubel *et al*., 1976). The mapping and development of the ocular dominance columns and their potential plasticity continues through development and is shaped by visual experience (Espinosa and Stryker, 2012).

After 38 to 40 weeks of gestation, the infant's visual system becomes light-sensitive and requires specific visual experiences for further development. This critical development period is during the first three years of life. For optimal visual development, infants need indirect light on objects, focus, attention, novelty, and movement (Graven and Browne, 2008). Colour perception develops after 2 to 3 months (Teller, 1998). Face recognition develops in the first 6-12 months of life and continues to develop throughout early development as cortical regions mature associated with facial recognition and classification in the fusiform gyrus (Behrmann *et al*., 2016).

Amblyopia

Amblyopia is the reduction of vision with no obvious organic cause and can be the result of deprivation of a clear image due to uncorrected refractive error, an opacity in the ocular media, or misalignment or control of oculomotor eye movements, or a combination of these factors (Levi, 2020; Webber, 2018). Visual or form deprivation results in changes in visual cortical neurons, with structural changes in the LGN and visual cortex (Levi, 2020) and a reduction in the number of binocularly driven visual cortex neurons (Jefferis *et al*., 2015; Joly and Franko, 2014). There is residual neural plasticity in the visual cortex that extends into early adulthood, with adults still able to improve VA in amblyopia (Rahi *et al*., 2002).

Amblyopia was initially considered to be a condition affecting just one eye, it is increasingly now being recognised as a binocular issue, leading to a growing number of studies that focus on binocular disorders. Joly and Franko (2014) in their review report recent evidence of deficits in the parieto-occipital and temporal cortex areas responsible for depth perception (Lui *et al*., 2004), but there is limited evience that binocular based therapies are superior to conventional therapies including patching (Borra *et al*., 2008).

1.3 Classification of Vision Impairment

The categorisation of VI by organisations typically follows the definitions established by the WHO, with VA ranging from 6/12 to 6/18 (0.30-0.50 logMAR) classified as mild VI, and VA between 6/18 and 6/60 (0.50-1.00 logMAR) classed as moderate VI. Severe VI is defined as achieving a VA level that is between 6/60 and 3/60 (1.00-1.30 logMAR). Total blindness is characterised by binocular VA of less than 3/60 (1.30 logMAR).

In many countries, best corrected distance VA less than the threshold of 1.00 logMAR (equivalent to 6/60 or worse) qualifies an individual as being legally ‘blind’, thereby making them eligible for various support mechanisms, including the Blind Pension in Australia, Federal and State Benefits in the United States, or the Disability Living Allowance in the United Kingdom.

Globally, it is estimated that approximately 1.4 million children suffer from blindness, with an additional 19 million who are classified with a VI with inherited retinal conditions accounting for an estimated 31% of these cases (Chong *et al*., 2019; Gilbert and Foster, 2001; Solebo *et al*., 2017). The incidence rates of VI vary based on the economic status of countries, ranging from 0.1 per 1,000 children in high-income nations, to 1.1 per 1,000 in their lower-income countries (Gilbert *et al*., 1999). In developed countries, the predominant causes of VI in children are cortical vision disorders, anomalies in the optic nerve, albinism, and inherited retinal dystrophies (Chong *et al*. 2019, de Verdier *et al*., 2018; Gilbert *et al*., 1999; Mitry et al., 2013, Rahi and Cable, 2003; Shirley et al., 2017; Solebo *et al*., 2017). Among preventable causes, retinopathy of prematurity (ROP) cataracts, glaucoma, and non-accidental injuries are the most frequent (Blohme and Tornqvist, 1997; Rahi *et al*., 2010; Solebo *et al*., 2017).

1.4 Visual Performance

Measures of visual performance may be classified according to tests of ***visual function*** that assesses the working ability of the eyes and visual system. Visual function assessments can include measures of VA, contrast sensitivity, visual fields, and ocular motor balance or motility. Tests for vision function usually involve controlled environments and standardised procedures, providing quantifiable measures that are related to absolute thresholds of visual discrimination such as visual resolution (acuity) or discrimination thresholds (visual fields). These indices can then be used to categorise the extent of VI based on clinical definitions.

In contrast, ***functional vision*** describes the way in which the eyes and vision perform during real world visually guided tasks, such as reading, watching television, or playing sports. The concept of functional vision is therefore concerned with daily activities and tasks that require vision and is context-dependent, being influenced by factors such as lighting conditions, distance, and the emotional or cognitive state of the individual (Bennett *et al.*, 2019; Colenbrander, 2005). Functional vision may be a more appropriate measure with which to evaluate an individual's visual performance with a VI that will affect activities of daily living.

VA is commonly used as the main clinical measure of visual function and is used as a determinant for driving and vocational tasks and is often used as an outcome measure following interventions such as cataract surgery (Hecht *et al*., 2023), or clinical trials (Beck *et al*., 2007). Importantly VA (and/or visual fields) is used to determine the level of support a child with a VI is eligible to receive. For example, a child in South Australia with VA of 1.00 logMAR (6/60) or a “severe” field restriction, would be eligible for the highest level of support (level 8) which in 2022 was AUD$54,132 (2022 School Resource Entitlement Statement). However, distance VA measures can be variable, particularly in children, depending on testing methods (Maguire, 2007; McGraw *et al*., 2000). Therefore, the reliance on VA may not provide the most appropriate measure of visual function such as reading or navigating the classroom environment. This thesis will explore if there are more suitable measures of visual ability that better describe the appropriate level of support a child with a VI may require in the classroom.

The notion of a difference in visual function (VA, fields) and functional vision (reading performance) was defined by Colenbrander (2005), who made the distinction between visual function and functional vision. Visual function relates to direct measures of the visual systems physiological capabilities, such as VA, whilst functional vision is concerned with the performance of visual tasks such as reading or drawing (Colenbrander, 2005). Thus, any interventions for students with a VI should be targeted to improve functional vision to improve the quality of life or level of participation in activities, whether that be education, the workforce, or recreational pursuits. Therefore, the development of appropriate structured tests of functional vision are required so that any interventions aimed at improving these measures can be formally evaluated. In agreement with this contention, Alam *et al*., (2022) using a Delphi process consisting of a panel of a panel of 38 experts in low vision (which included ophthalmologists, optometrists, orthoptists occupational therapists, orientation and mobility specialists and researchers), recommended that the referral for low vision services and support should be based on the impact of low vision and well-being, and that VA should be a secondary consideration (Alam *et al*., 2022).

1.5 Samuel Genensky

Samuel Genensky grew up in Massachusetts during the 1930's when children born in the state had diluted silver nitrate drops instilled into their eyes to prevent transmission of syphilis from their mother. Unfortunately, in Samuel's case, the drops were not diluted, and his vision was lost due to corneal scarring. Despite learning Braille, he preferred to use the limited vision he had, and in 1958 received a PhD in applied mathematics from Brown University where he developed the first closed-circuit television system to assist him with reading. A renowned advocate for blind and VI individuals, he asserted the need for a functional classification system. One which would:

> ***"Clarify the nature of visually impaired, improve public understanding of their capabilities and needs, improve the quality and quantity of services they receive, increase their chances of receiving a high quality and relevant education and achieving economic independence."*** (Genensky, 1971).

Genensky (1976) was also one of the first to suggest that VA measured in low luminance testing rooms was an unsuitable proxy for visual performance. Genensky (1976) also noted that measures of VA in individuals with VI were unreliable given the effect of luminance on VI and therefore VA was not an appropriate measure of an individual's real world functional ability under different luminance conditions.

Some early clinical guidelines were developed for a child with a VI by Corn and Koenig (1996). However, these guidelines were developed before the advances in computer assisted learning in the classroom and were based on classroom task-based subjective observations of how a child with a VI uses their vision in functional tasks. Functional vision has also been investigated using instruments, such as the visual functioning questionnaire (Massof and Fletcher, 2001) to better evaluate the impact of a VI on health related quality of life (QOL), which may not fully capure the impact of the wide range of conditions that can cause a VI and their different impacts within the classroom (Tabrett and Latham, 2011).

1.6 Low Vision and Education

Educational achievement is closely connected to visual capability. Students with a VI tend to have suboptimal educational results and are at a greater risk of exclusion from educational settings (Burton *et al*., 2021). Previous studies comparing academic grades or test results have demonstrated that the correction of uncorrected refractive error in students can significantly enhance academic performance (Toledo *et al*., 2010; White *et al*., 2017) supporting the need to provide the best possible vision for students with a VI.

1.61 Reading and low vision

VA measurements involve the identification of a single letter optotype, whereas reading is a more complex task drawing on extrastriate regions to comprehend the text, then perform visually guided saccades using motor programs that are integrated with ocular motor control (Moss *et al*., 2011). Reading involves the eyes undergoing small rapid saccades (eye movements) across text, then short fixations on a word (Agarwal *et al*., 2016). Text is read using a combination of skills taught in early childhood, including phonic awareness, word decoding and sight word analysis (Siegel, 1993). Since the visual requirement for effective reading requires small rapid saccades and short fixations, reading can be heavily impacted by motor coordination and visual processing ability (Vernet *et al*., 2022).

Students with VI have been shown to use the same mechanisms of reading as individuals with normal vision (Bosman *et al*., 2006; Gompel *et al*., 2004; Loh *et al*., 2024), but this can be significantly impacted by motivation (Wigfield *et al*., 2016). Reading motivation is multifaceted and can be influenced by intrinsic motivation (internal drive), self-efficacy (self-belief), extrinsic motivation (due to external factors - such as reward or recognition), and social motivation (social factors - such as the desire to fit in) (Guthrie, 2009).

Legge *et al*., (1985) investigated the general factors that affect reading ability in VI. The authors reported that the primary mechanisms affecting reading ability was having normal central visual fields and the clarity of the ocular media. Participants were asked to read text aloud from a monitor and their reading rate computed in words per minute (WPM) - by increasing the rate at which text was scrolled across the screen. They also investigated how letter size affected reading speed and accuracy. They found that if words were very large reading rate was slower, but as the words became smaller reading speed increased and reading rate was maintained across several print sizes, when the characters approached resolution limits, then reading speed reduced dramatically as illustrated in **Figure 1.13** showing reading speed as a function of word font size.

Figure 1.13: Reading Speed and Font Size

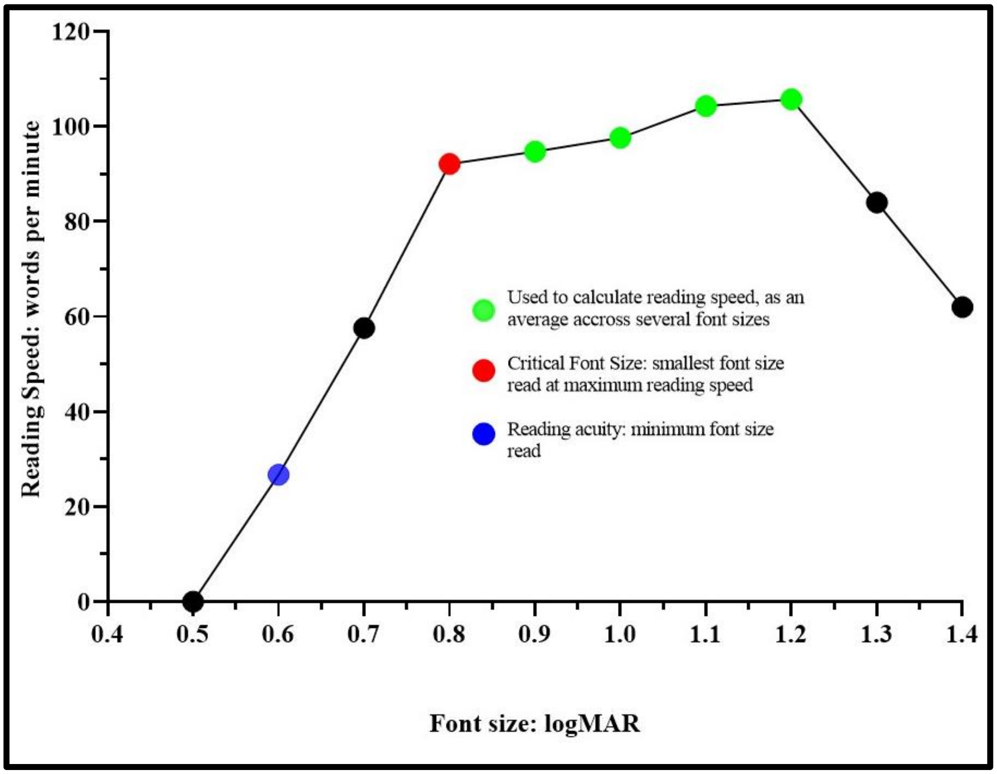


Figure 1.13. Plot depicting the relationship between font size and reading speed. Initially with large font sizes (represented by black dots), the reading speed is slower because the reader can see fewer words per page and is required to scan more. As the font size decreases, allowing for more words per page, the reading speed increases. This increase in reading speed continues until an optimal reading speed is reached (indicated by green dots). At this point, reading speed plateaus and remains constant, even if the font size continues to decrease. The red dot indicates the critical print size – the smallest font size read at maximum reading speed – before reading speed starts to decline. As font size reduces further and approaches close to the resolution limit of the reader's vision, reading speed declines rapidly.

In addition, when the authors reversed the contrast of the words so that the text was displayed in reverse polarity (RP) - white font on a black background - then participants with cloudy media (cataract, corneal scarring, or vitreous debris) could read 10-50% faster with RP than they could with normal polarity (NP) - black writing on a white background. This improvement was not demonstrated in any of the participants with clear media, so it was surmised that the improvement with RP was due to reduced light scatter and veiling glare (Legge *et al*., 1985).

To further explore this finding, this thesis examined the impact of text polarity to determine whether it could improve the reading performance of students with VI (See **Chapter 4.4**).

Another, factor identified by Legge *et al*., (1985) was the 'sample density' or the number of characters that are available to VI readers and is thought to be less than that available to normal vision readers, possibly due to visual field loss and/or poor contrast sensitivity. Other important factors identified were the window size (the amount of text or the number of words that a reader can perceive and process during a single fixation), character spacing and the effect of crowding, central visual field extent and the clarity of their ocular media.

To address some of these factors, Legge *et al.*, (1985) further examined whether the maximum reading rate could be predicted from clinical measures of visual function including VA and visual field extent. They performed multiple regression analysis using measures of near and distance VA, media clarity (clear or cloudy), and visual field size using three categories: 1. intact, 2. central loss (scotomas covering all or part of the central 5 degrees), or 3 peripheral loss (one or more scotomas in non-central areas), as predictors for optimal character size and maximum reading rate. They found that the best predictors for the optimal word font size was near acuity which accounted for

76% of the variance in reading speed. The best predictor of reading rate was the extent of central fields which accounted for 59% of the variance in reading rate, and if the central fields were intact then the next best predictor of reading rate was the ocular media clarity, accounting for only 5% of the reading rate variance.

1.62 Reading ability in children with a vision impairment

Reading and literacy skills are crucial to educational development with the foundations of these fundamental skills typically beginning before pre-school. The stories read, along with the childhood games played may be different for children with a VI compared to a normal sighted child because some parents may feel reluctance around reading and playing with children who are blind or have a VI, which may impede their reading and literacy levels (Keil *et al.*, 2017). This could be influenced by a variety of factors, both psychological and practical (hide and seek or peek-a-boo for example). Reservations are generally based on misconceptions or lack of information, rather than objective evaluations of the child's needs or capabilities. Thus some parents may presume that because a child cannot see, they will not benefit from being read to. They might feel that the experience is inherently visual and therefore unsuitable for a child who cannot see any pictures or text.

Furthermore, parents may find the act of reading to a child that is blind or has a VI emotionally challenging, particularly if they have not yet fully come to terms with their child's disability and may not have receive adequate support at the time of diagnosis (Rahi *et al.*, 2004). The process might serve as a painful reminder of the child's condition, leading them to avoid it altogether.

Parents may worry that talking about or describing visual elements in a book could make the child feel excluded or highlight what they are missing, thereby causing emotional distress. The availability of appropriate materials in different languages, such as large print books or audiobooks, may be limited, leading parents to think that reading activities are not feasible, or parents may not be familiar with alternative reading methods, that are available (Rahi *et al*., 2005). In some societies, disability can be stigmatised, and parents may avoid drawing attention to a child's VI, even in the privacy of their home. Such attitudes may extend to educational activities like reading as reported by the United Nations Children's Fund (UNICEF).

Understanding these potential barriers can be the first step in educating parents about the benefits of reading to children with a VI. Activities such as storytelling are universally important for child development and can be adapted to meet the needs of all children, regardless of their physical capabilities. Reading to a child who has a VI is beneficial. Reading aloud can provide the same opportunities for bonding, language acquisition, and cognitive development as it does for sighted children (Grumi *et al*., 2021; Roe *et al*., 2014).

For children who have a severe VI, many books are available in Braille or other tactile formats. Storytelling can be a powerful tool for intellectual and emotional growth, and the act of listening can engage the child's imagination just as it would a normally sighted child listening to a story. Parents who read to their child who has a VI can use the opportunity to discuss the book's themes, characters, or settings in detail, providing the child with a richer understanding of the world. This can be done while also incorporating tactile experiences or using descriptive language that appeals to the other senses, thus enriching the child's understanding and experience of the story. It can also serve as a steppingstone for encouraging literacy through Braille or other assistive technologies (Cooper, 2005; Fekonja-Peklaj *et al*., 2010; Miller and Pennycuff, 2008; Roe *et al*., 2014).

1.7 Low Vision and Educational Support in South Australia

Support for children with a VI at school, in the state of South Australia, is typically based upon clinical measures of high contrast distance VA which is the historically accepted measure of visual function. The entry level for support and level of support a child receives is based on their VA and/or a measure of visual field extent, if available.

In South Australia, over two hundred and fifty children with a VI, aged 5-18 years, are supported by specialist teachers within the Statewide Support System for students with a VI under the South Australian Education Department (SASSVI, 2023).

The South Australian School for Vision Impaired caters for children with a higher degree of VI from reception to year six. Eligibility for enrolment is based on diagnosis of a VI by an ophthalmologist, based on best corrected distance VA in the better eye (or binocular vision) of less than 6/60 (1.00 logMAR) on a letter chart and/or a ‘severe’ field of vision constriction (SASSVI, 2023). Children with a less severe degree of VI (6/18 to 6/60) and students older than year 6 are supported by specialist teachers through the Statewide Support Service in mainstream education. All students have been investigated for optimal refractive correction and an Ophthalmology assessment and report is required for referral to specialist vision support services. Specialised vision support teachers ensure students have access to and can participate in all curriculum areas within their school environment. This includes classroom learning support, (including Braille teaching if required), access technology assessment and support, and specialised adaption of sports. SASSVI school also houses an Accessible Format Production unit producing braille and accessible resources.

Eligibility for statewide support within any school within South Australia requires a VI diagnosis by an ophthalmologist and recorded best VA less than 6/18 on a distance vision chart or a "restricted field" (SASSVI, 2023).

Educational learning within a classroom environment requires a high proportion of vision tasks that are predominantly near based (Narayanasamy *et al*., 2016) and VI results in differing degrees of impact on visual ability, depending on the cause of vision loss. The impact on visual ability can also vary depending on the child's environmental learning conditions (Naipal and Rampersad, 2020).

It is often a confounding task for a support teacher to understand the functional implications of VA and the underlying pathological cause within a classroom setting. Support teachers mention that they often undertake a tedious process of searching for definitions and never really connecting with an understanding of the student's VI or their visual behaviours (personal communication). Ophthalmology reports that are given to classroom teachers are often a brief statement of the students' VI but have no information about how the child may function visually within the classroom or how to best support the child.

The main aim of this thesis was to examine the functional visual capabilities of students with a VI within their educational environment. Given that educational assistance eligibility in South Australia is currently determined by visual function metrics, (distance VA), this thesis initially aimed to ascertain whether these metrics accurately reflect a student's functional vision in a classroom setting. Subsequently, functional vision metrics were investigated to identify those that represented a student's visual abilities within an educational context. The aim was to develop a comprehensive assessment framework that would provide support to be tailored in the classroom around the individual's functional vision to best support the individual's accessibility to the curriculum. The proposed framework, based on functional measures of vision, may offer an additional dimension with which to classify children with a VI and further guide the appropriate level of support required throughout education.

1.8 Study Questions

- **How do standard Visual Function measures, such as VA, portray the functional state of vision from students with a VI?**
- **What measures of visual ability best characterise the state of functional vision in students with a VI (and specific pathologies)?**

To explore these questions a conceptual framework outlined in **Figure 1.13** was used to guide this thesis. The conceptual framework begins with the current VI classification and support system using visual ability based on VA and extent of the visual fields. Subsequent steps involve conducting functional vision assessments, followed by the provision of customised recommendations to teachers and parents to address deficits in functional visual ability within the classroom. VA was then correlated with these functional measures to evaluate its representativeness of functional ability. The final stages included the development of an assessment framework that encompassed tests capturing important aspects of functional ability in the classroom and culminating in a proposed alternative classification model for VI based on the functional vision performance of the VI individual.

1.9 Conceptual Framework

The conceptual framework for this thesis outlines the essential phases, beginning with the evaluation of functional vision. It involves the examination and correlation of vision function (VA) with functional vision metrics, leading to the creation of an assessment framework that accurately reflects functional vision. This thesis will also propose a novel classification structure and offer clinical guidelines to facilitate optimal access and ensure a fair learning environment for students with VI.

Figure 1.14: Proposed Conceptual Framework

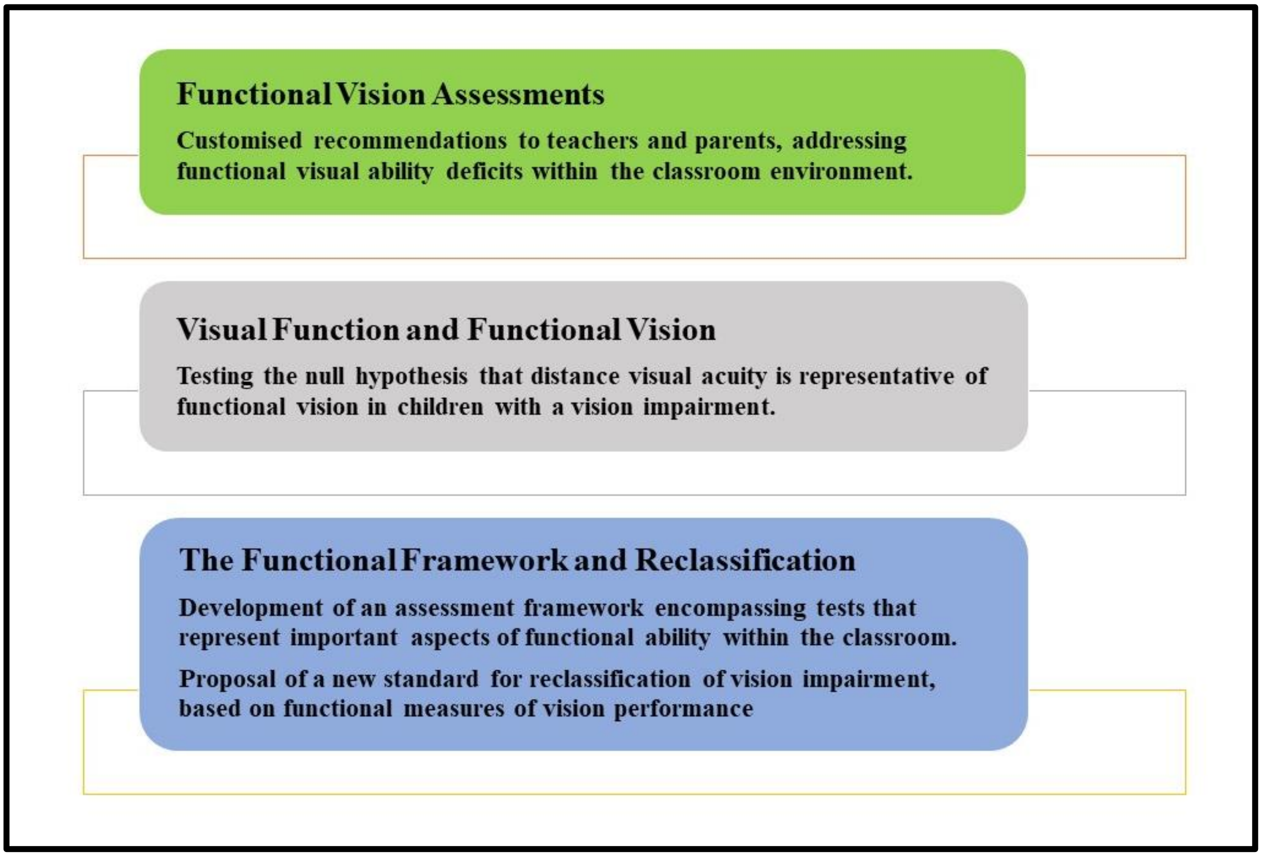


Figure 1.14. Flow diagram illustrating the proposed conceptual framework that forms the basis of this thesis. Results of the functional assessments and interviews alongside feedback from interventions from students and teachers will feed into the development of a clinical framework designed to be implemented to support the students.

1.10 Thesis Hypotheses and their Contributions to new Knowledge

Building on the framework the following Null hypotheses were tested:

- Distance VA is representative of functional vision in children with a VI.

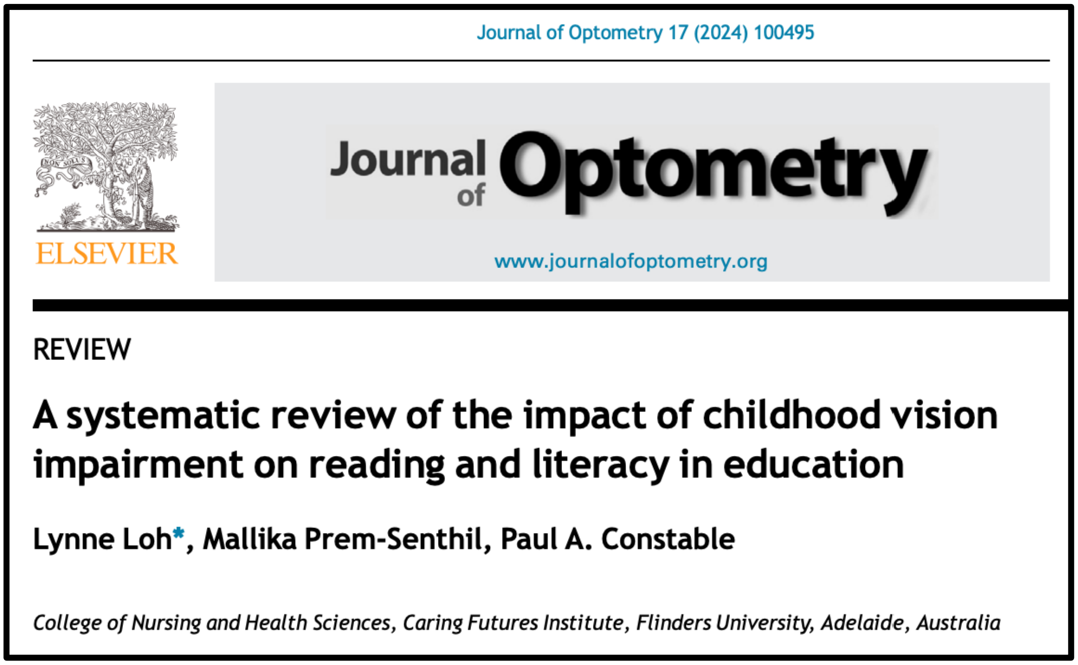
- Customised recommendations to teachers and parents of students with a VI will not support the student's access to education in the classroom.

Based on these outcomes this thesis will aim to contribute to new knowledge by:

- Develop an assessment and support framework that is representative of functional ability for children with a VI.
- Propose an alternative model that meets the individual needs of the child that aligns with their functional vision.
- The development of support guidelines to provide optimum access to the curriculum for students with a VI and enable an equitable learning environment.

CHAPTER 2 : SYSTEMATIC REVIEW

This section contains material from published work


Journal of Optometry 17 (2024) 100495

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REVIEW

A systematic review of the impact of childhood vision impairment on reading and literacy in education

Lynne Loh*, Mallika Prem-Senthil, Paul A. Constable

College of Nursing and Health Sciences, Caring Futures Institute, Flinders University, Adelaide, Australia

Loh L, Prem-Senthil M, Constable PA. A systematic review of the impact of childhood vision impairment on reading and literacy in education. *J Optom*. 2024;17 (2). doi:10.1016/j.optom.2023.100495

This part of the thesis evaluated the literature regarding the influence of childhood VI on reading, literacy, and educational performance within the classroom setting. The systematic review was undertaken to better understand the previous literature that explored the way students with a VI learn to read in comparison to those with normal visual function. The systematic review also explored the reported impact of VI on learning and discussed how this may affect overall educational outcomes in this group.

The aim of the systematic review was to establish the current findings with respect to the impact of VI on reading ability in children. The systematic review was registered with Prospero- an international register of systematic reviews:

(https://www.crd.york.ac.uk/prospero/) database number: CRD42020172342

Study link:

https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020172342

See also **Appendix 1** for systematic review summary.

2.1 Background

Childhood VI is a condition that can significantly impact all areas of a child's development, with education playing a critical role in determining their overall quality of life (Decarlo *et al*., 2012) and long term social and economic position (WHO, 2019). A child with a VI is more likely to live in deprivation, have negatively impacted emotional and social wellbeing, and have reduced opportunities for future employment, which contributes to an increased financial burden on society through support (Cumberland *et al*., 2016; Gilbert *et al*., 1999; Keil, 2003; Rahi and Cable, 2003; Rahi *et al*., 2010;). Children with a VI are also more likely to have autism spectrum disorder as a comorbidity with their reduced vision (Do *et al*., 2017).

The WHO Report on Vision highlighted the importance of good vision for the development of children and adolescents (WHO, 2019). From cognitive and social development, motor skills, coordination, and balance, to the ability to access education and achieve optimum academic success. This ultimately facilitates participation in the workforce which contributes to economic productivity and fosters a positive sense of identity for the individual. The prevalence and common causes of VI have been discussed in **Chapter 1.3**.

The educational challenges facing these children with a VI will vary considerably and their overall achievement may be shaped by the functional consequences that their VI has but also by the quality of the educational support and adjustments they receive to improve their access to classroom learning materials (Loh *et al*., 2022; 2023). To accommodate students with a VI, a common classroom adaption involves enlarging the font size to enhance reading comfort. Whittaker (1993) investigated the visual requirements for reading and determined four factors that affected reading rate: acuity reserve (print size compared with minimum reading acuity), contrast reserve (print contrast relative to contrast threshold), field of view, and the presence and size of any central scotoma. Bailey *et al*., (2003) demonstrated that the size of reading print was a significant factor in reading speed, emphasising that the ability to optimise font size for children provided a better opportunity for increased reading speed. However, enlarging the font size too much can decrease reading speed because the letters were imaged too far in the periphery of the retina, with poor resolution, resulting in a slower reading speed.

Several studies have examined the consequences of uncorrected refractive error and the negative impact this can have on academic achievement. White *et al*., (2017), found 30% of 109 grade 3 students in Australia, failed visual screening tests for VA and binocularity. Narayanasamy *et al.*, (2014; 2015) used simulated refractive errors and demonstrated that even low levels of hyperopia and astigmatism resulted in reduced reading speed, reading accuracy, comprehension, and visual processing, highlighting the importance of optimal vision for achievement.

Upon leaving education, and despite employment opportunities improving over time for students who are blind and/or have a VI, a gap still exists between the employment rates of individuals who are blind or have a VI compared with normally sighted individuals - which are still less than 50% (McDonnall and Sui, 2019). Individuals who have a VI are at greater risk of suicide later in life compared to the general population, which is further increased in those reporting poorer self-rated health issues (Lam *et al*., 2008). Further studies have found that reduced vision results in a significant impact on self-rated health as adults (Cumberland and Rahi, 2016; Wang *et al*., 2000). A child with a VI is more likely to be hospitalised or die during childhood (Crewe *et al*., 2013; Gilbert and Foster, 2001) and score lower on the Health-Related Quality of Life (Boulton *et al*., 2006; Crewe, *et al*., 2013; Khadka *et al*., 2012; Lam, *et al*., 2008; Tadić *et al*., 2013; Wang *et al*., 2000).

2.2 Methods

Search Strategy

A search of six databases was performed for articles from 1946 to May 1st, 2023, in: Ovid Medline, Cochrane Library, Emcare, Web of Science, Scopus, Education Resources Information Centre. References of all relevant articles were hand searched. See **Table 2.1** for search terms used in the databases. The search terms were: Child* was used to cover both child, children, children's. Blind* produced results from blind or blindness. Improve* produced results from improve or improvements. School* produced results from school, schools, schooling and Visual* included Visually. The full search strategy is included in the **Appendix 1**.

Table 2.1: Search keywords and search terms used.

Keywords	Search terms
Children	Child*, adolescent, youth, young people
Vision Impairment or blindness	Visual* acuity, visual* performance or Vision impaired, Visual* impaired vision disorders, blindness, low vision
School	School*
Classroom	Class*
Education	Education*
Literacy	Literacy, reading, writing
Education Performance	education performance, school performance, classroom performance, academic performance, education* impact, school impact, classroom impact, academic impact, education* improvement, school improvement, classroom improvement, academic improvement "education* success" or 'school success" or "classroom success" or "academic success"}

Table 2.1. Searches were limited to human subjects and conducted in the English language up until May 2023.

2.2.1 Inclusion criteria

Trials or studies included in the systematic review involved children aged 5-18 years who had received a pathological vision diagnosis as blind or having a VI according to the WHO criteria.

The trials or studies focused on examining the effects of VI on academic and school performance, specifically in areas such as literacy (including reading and comprehension), writing skills, access to information, and overall academic performance.

2.2.2 Exclusion criteria

Studies were excluded if the study group included those with a co-morbidity, such as additional sensory or cognitive disability (deaf or intellectual disability), or if they had a diagnosed reading disability (dyslexia). Studies from developing countries were not included due to variable levels of education and healthcare available within those countries, making it challenging to draw direct comparisons with services in Australia (Courtright *et al*., 2011; Eleweke and Rodda, 2002; Lynch *et al*., 2011). In addition, studies involving preschool-age children were excluded, because the main study questions were aimed at examining the impact of VI on learning specifically within the primary and secondary school years.

2.2.3 Study Selection

Database searches revealed 1262 articles, with an additional article identified by personal communication. Articles were imported into EndNoteX9 (Clarivate, UK) and after duplicates were removed and seven additional papers identified from hand searching, 1043 titles and abstracts were screened for ineligibility based on title and abstract. Sixty-one remaining articles underwent full-text screening against eligibility criteria by two authors, with the third author available if agreement was not reached. Of those articles, seven papers were eligible for inclusion. **Figure 2.1** shows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for the search of included articles.

Although the search strategy identified articles that investigated measurable academic outcomes and the impact on mathematical grades, these studies investigated the impact of uncorrected refractive error in children and were excluded (Hannum and Zhang, 2012; Hark *et al*., 2020; White *et al*., 2017). The papers included in the systematic review were therefore restricted to those that investigated reading and literacy skills in children specifically with a diagnosed VI that was not caused by an uncorrected refractive error (ametropia).

Figure 2.1: Literature search.

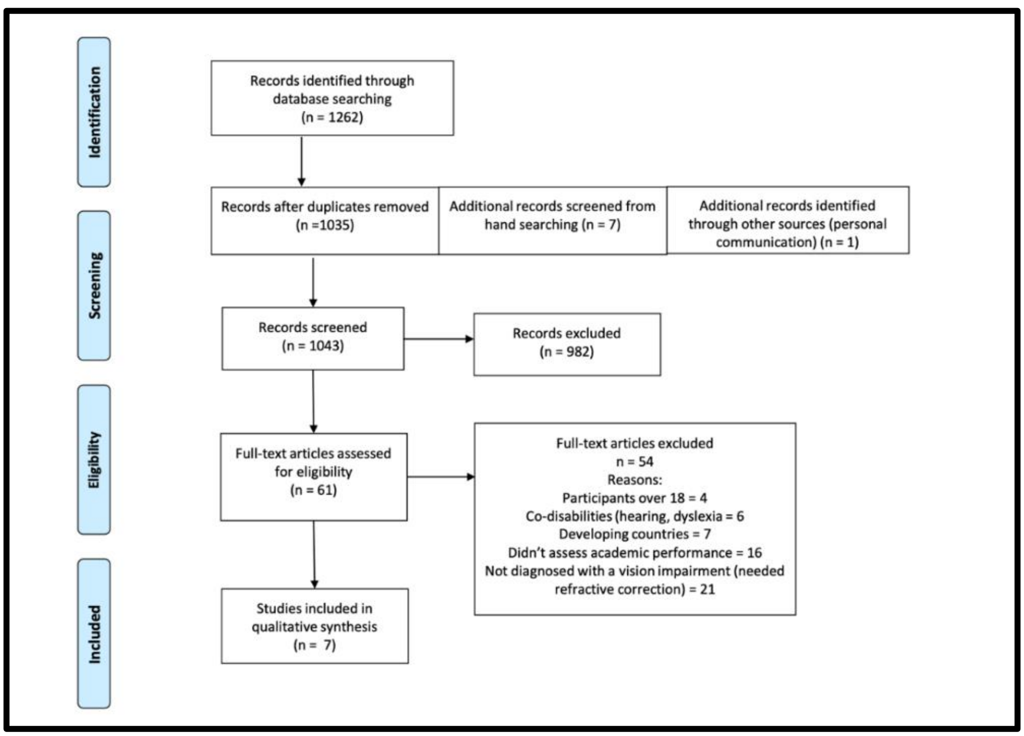


Figure 2.1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of literature search with results showing the number of included and excluded studies following screening.

2.2.4 Quality appraisal

To evaluate the quality of the studies, the Critical Appraisal Skills Program (CASP) was used because it has separate checklists to evaluate the quality of varying study methods (CASP, 2011). Studies were included if they were deemed valid following appraisal with the relevant CASP checklist. CASP does not use a standardised numerical scoring system. Instead, it employs a series of questions designed to guide the appraising through a critical process. Questions were answered as a “yes”, “no” or “can’t tell” response. To enable the selection of studies, a scoring system was designed as a tool to confirm agreement between the authors and to determine the overall quality of the included studies.

2.3 Results of Systematic Review

2.3.1 Included studies

Using CASP themes, studies were assessed for clear study focus, appropriate methodology, confounding factors, and the validity of the results. Limitations and risk of bias were also considered and an assessment of high, medium, or low bias was determined as shown in **Table 2.2**. Studies were scored on quality with green scoring 2 points, yellow 1 point, and red 0 points. Scores from all three authors were compared and discussed until agreement was reached. Scores were then converted into percentage values with all articles achieving a quality score of over 70%. Small participant numbers, recruitment methods, methods of VA measurement or reading analysis measurement and missing data from studies were the main causes of bias. Two studies did not specify VA measures but were determined eligible for inclusion as all participants had been previously diagnosed with a VI by an ophthalmologist.

Table 2.2: CASP checklist assessment

Study	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**Score**
Corn *et al*., (2002)	🟢	🟢	🟢	🟡	🔴	🟡	🟢	71%
Douglas *et al*., (2004)	🟢	🟢	🟡	🔴	🟢	🟢	🟡	71%
Bosman *et al*., (2006)	🟢	🟢	🟡	🟢	🟢	🟢	🟡	86%
Gompel *et al*. (2004)	🟢	🟢	🟡	🟡	🟢	🟢	🟡	76%
Lueck *et al*., (2003)	🟢	🟢	🟢	🟡	○	🟢	🟢	92%
Lovie-Kitchin *et al*. (2001)	🟢	🟢	🟢	🟢	○	🟢	🟡	92%
Huurneman *et al*., (2016a)	🟢	🟢	🟢	🟡	🟢	🟢	🟢	93%
a, b, c	**Yes** 🟢		**Not sure** 🟡		**No** 🔴		**N/A** ○	
d, e, f, g	**Low** 🟢		**Medium** 🟡		**High** 🔴			

Table 2.2. CASP checklist assessment including themes of (a) Clear Study Focus (b) Appropriate Methodology (c) Validity of Results (d) Recruitment Bias (e) Control Bias (f) Outcome Bias (g) Confounding Factors, (N/A) not applicable.

Study designs varied including one longitudinal study investigating the impact of optical devices over a four to six-month period (Corn *et al*., 2002), three case control studies (Bosman *et al*., 2006; Douglas *et al*., 2004; Gompel *et al*., 2004), two case series (Lovie-Kitchin *et al*., 2001; Lueck *et* *al*., 2003) and one interventional study using crowding training (Huurneman *et al*., 2016a). VAs ranged from 0.10-1.70 logMAR, with two papers not specifying VAs (Douglas *et al*., 2004; Gompel *et al*., 2004). Participant numbers varied from 6 to 158, and ages also varied from 6-18 years. VI children were recruited predominantly from either mainstream schools or specialist VI institutes/sites. Countries included The Netherlands (3), The USA (2), England (1) and Australia (1). A summary of demographics is detailed in **Table 2.3**.

Table 2.3:Demographics of included participants

Study **Country**	**Number of Participants (M:F)**	**Age in years** **SD: standard deviation**	**Visual Acuity of Participants Diagnosed with a Vision Impairment**	**Visual Acuity Test Used**
Corn *et al*., (2002) USA	*n*=185 Vision Impaired (122M:63F).	Average age 10.54 (SD 3.85)	20/32-20/1000 (logMAR 0.20-1.7) Groups of Low Vision severity: Near normal 20/32-20/63 (*n*=28)/ Moderate 20/80-20/180 (*n*=69)/ Severe 20/200-20/400 (n=72)/ Profound 20/500-20/1000 (*n*=15)	Feinbloom Low Vision Chart at 10 feet.
Douglas *et al*., (2004) England	*n*=50 25 Vision Impaired. 25 Normal Vision. (14M:11F)	Low vision 6:5-14:3 (mean 10.4). Normal Vision 7:8-10:6 years (mean 8.67)	Visual Acuity not specified. Diagnosed vision impairment.	Not specified
Bosman *et al*., (2006) The Netherlands	n=54 18 Vision Impaired (6M:12F).	Low vision: mean age 10.5.	20/50-20/250 (logMAR 0.4-1.10)	Visual acuity test not specified

	26 Normal Vision: 18 Age-matched. 18 Reading-matched.	Reading matched normal Vision: mean age 9. Age matched 10.4.		Lea Symbol Distance Visual Acuity Test.
Gompel *et al*., (2004) The Netherlands	Total 120 40 Vision Impaired. 80 Normal Vision: 40 Age-matched. 40 Reading-matched.	Ages not specified. Participants selected from a previous study: mean age 9.5	Visual acuities not specified. Diagnosed vision impairment.	Visual acuity test not specified
Lueck *et al*., (2003) USA	*n*=6 (3M:3F).	8-10	Distance Visual Acuity: 20/160-20/600 (logMAR 0.9-1.50) Reading Acuity: 20/66-20/1162	Lea Symbol Distance Visual Acuity Test.
Lovie-Kitchin *et al*., (2001) Australia	*n*=75 Vision Impaired (42M:33F)	7-18	Distance: 0.10-1.28 logMAR Near Visual Acuity: 0.12-1.47logMAR (N1.5-N24 at 10cm).	Bailey-Lovie letter chart at 3m (or closer if visual acuity was less than 6/120)
Huurneman *et al*., (2016a) The Netherlands	*n*=36 Vision Impaired	Albinism: 9.25±19 months Infantile nystagmus: 9.1±18 months.	Albinism: 0.47±0.30 logMAR uncrowded, 0.66±0.05 logMAR crowded. Idiopathic Infantile Nystagmus: 0.25±0.17 logMAR uncrowded, 0.46±0.05 logMAR.	Crowded and uncrowded Landolt C, measured at 5m for distance and 40cm for near.

Table 2.3. Demographics of included participants including participant numbers, country, participant ages, visual acuity ranges and visual acuity tests used – where specified: M: Male; F: Female; *n*: Number of participants; SD: Standard Deviation. All reading tests were validated

standardised tests within their respective countries and were selected as appropriate for the age range of students that participated.

Due to the large variation in participant numbers, ages, VAs, causes of VI, methodological differences and outcome measures, a direct quantitative comparison of the findings was not possible. All papers investigated reading performance and used varying methodologies to determine reading speed as a primary outcome measure. Alternative measurements of reading ability were comprehension (Corn *et al*., 2002; Douglas *et al*., 2004), reading acuity/print size (Bosman *et al*., 2006; ; Gompel *et al*., 2004; Lueck *et al*., 2003) and reading accuracy or reading errors (Douglas *et al*., 2004; Huurneman *et al*., 2016; Lovie-Kitchin *et al*., 2001) as shown in **Table 2.4**.

Table 2.4: Summary of outcome measures and reading tests used

Study	Outcome Measures	Test Used
Corn *et al*., (2002)	Change in reading and comprehension ability before and after using optical devices. (153 students [82.7%] had assistance of specialist teachers of vision impairment).	Silent and oral reading speeds and comprehension levels measured using the Burns and Roe Informal Reading Inventory (1993)
Douglas *et al*., (2004)	Reading speed, comprehension and reading errors.	Neale Analysis of Reading Ability (NARA)
Bosman *et al*., (2006)	Speed of first letter phonology naming. Time and accuracy naming single words.	The Netherlands standardised reading-decoding one-minute test (Brus and Voeten, 1973)
Gompel *et al*., (2004)	Identification of constituent letters of a word and the processing of letter order information in words. Naming latency and accuracy recorded.	Standardised three-minute word decoding test (DMT, Verhoeven, 1995)
Lueck *et al*., (2003)	Reading speed and working distance for students with low vision.	MNREAD Acuity Charts
Lovie-Kitchin *et al*., (2001)	Reading rate (wpm) for each print size. Maximum oral reading rate. Near visual acuity: smallest print size read in LogMAR. Critical print size. Reading reserve.	Minnesota Low Vision Reading Test on printed cards.
Huurneman *et al*., (2016a)	Reading performance: acuity/ critical print size/ maximum reading speed (wpm)/ reading reserve/ Crowding Intensity. Administered crowding and uncrowded training to determine effect of training on reading performance.	Sentences of a Dutch Reading chart (LEOntienje) presented on a computer screen.

Table 2.4. Summary of outcome measures and reading tests used, including: **Critical Print Size**: Smallest font that can be read at maximum reading speed. **Reading Reserve**: ratio of critical print size to smallest font size read. **Crowding Intensity**: ratio of crowded acuity to uncrowded acuity. **Maximum Reading Speed** in words per minute (WPM).

2.3.2 Reading Speed

All seven included studies investigated reading speed and are summarised in **Table 2.4**. The majority analysed reading speed while reading continuous text (Bosman *et al*., 2006; Corn *et al*., 2002; Douglas *et al*., 2004; Gompel *et al*., 2004; Lueck *et al*., 2003), whereas one study investigated the speed of naming single words (Bosman *et al*., 2006). There was consensus amongst all studies that reading speed was slower in children with a VI compared with their age matched normally sighted peers, and common findings were that reading speed increased with age (Corn *et al*., 2002; Lovie-Kitchin *et al*., 2001), and with an improvement in VA (Lovie-Kitchin *et al*., 2001; Corn *et al*., 2002; Lueck *et al*., 2003) - although VA was measured at distance in two studies (Corn *et al*., 2002; Lueck *et al*., 2003), and near in one (Lovie-Kitchin *et al*., 2001). Two studies compared the reading speed of text to single words and discovered contradictory results, with one finding text reading faster (Lueck *et al*., 2003), and the other faster single words than reading text (Gompel *et al*., 2004).

2.3.3 Reading Reserve

Three studies investigated reading reserve - the relationship between minimum font size read and critical print size (the smallest font read at maximum reading speed). Reading reserves differed across all these three studies and ranged from 1.6-7.0 times (Lovie-Kitchin *et al*., 2001; Lueck *et al*., 2003) with results summarised in **Table 2.4**.

2.3.4 Comprehension

Two studies examined comprehension by children with low vision (Corn *et al*., 2002; Douglas, Grimley *et al*., 2004). It was found, in terms of reading ability, that students with a VI demonstrated a generalized lag in comprehension ability, compared to their normally sighted peers. Corn *et al*., (2002) additionally found an increase in comprehension ability following optical device use over a four-month period, which was more apparent in younger participants in grades 1-3 or primary school. Results of these studies are summarised in **Table 2.5**.

2.3.5 Reading Performance

Three studies investigated the reading processes adopted by children with a VI to cope with reading (Douglas *et al*., 2004; Gompel *et al*., 2004; Lovie-Kitchin *et al*., 2001). Douglas *et al*., (2004) found that the students with a VI tended to make more substitution errors than mispronunciation errors than the normally sighted group, which the authors suggested was due to guessing. Whereas the younger control group of normal vision readers made more mispronunciation errors than substitutions. However, these findings were contrary to the other two studies (Bosman *et al*., 2006; Gompel *et al*., 2004) that found reading processes were not significantly different to the students of the same reading-matched group and were slower but equally accurate. Gompel *et al*., (2004) also found that children with a VI relied more on sentence context than on word phonology. The summary results of these studies are shown in **Table 2.5**.

Table 2.5: Summary of main reading measures

Study	**Reading speed**
Corn *et al*., (2002)	Silent and oral reading speeds were slower than normally sighted peers. After using optical devices over 4 months, there was a significant increase in silent reading speeds – more apparent at lower year levels. Reading speed decreased with reduced visual acuity. Increase in reading rate with increasing year level.
Douglas *et al*., (2004)	Students with a vision impairment demonstrated a general lag in reading speed compared with normally sighted peers.
Bosman *et al*., (2006)	Students with a vision impairment were slower at reading single words than their normally sighted peers.
Gompel *et al*., (2004)	Reading speed for text and single words was slower in students with a vision impairment than normally sighted peers. Single words were read faster than text.
Lueck *et al*., (2003)	Reading speeds increased with increased visual acuity. Reading speeds decreased with decreasing print size. Reading speeds for text, faster than non-related words.
Lovie-Kitchen *et al*., (2001)	Reading rate increased with increasing age. Reading rate increased with improved near visual acuity.
Huurneman *et al*., (2016a)	Children with infantile idiopathic nystagmus had a lower reading speed compared with children with albinism – both read slower than their normally sighted peers. Following crowding training, both groups read faster.

	Reading Reserve
Lueck *et al*., (2003) Huurneman *et al*., (2016a) Lovie-Kitchen *et al*., (2001)	A reading reserve of 1.6 – 2.5x reduced reading speed. Recommended reading reserve of 3x to be used by children with low vision. Children with larger crowding extent required larger critical print size and reading reserve. Children with a lower near visual acuity had a smaller reading reserve. Recommended an optimum reading reserve of 4x. 56 subjects (75%) required a reading reserve of between 2.5-7x.
	Comprehension
Corn *et al*., (2002) Douglas *et al*., (2004)	General lag in comprehension level compared with normally sighted peers. An improvement in oral comprehension was demonstrated following optical device use for four months. Silent comprehension also improved over the four months period, but not as much as oral. General lag in comprehension level compared with normally sighted peers.
	Reading process, reading accuracy, and reading errors
Douglas *et al*., (2004) Bosman *et al*., (2006)	Children with a vision impairment more likely to make substitution errors than mispronunciation errors. Reading behaviour of low vision group same as (younger) reading matched group, but lower than age-matched group. Reading process of students with low vision differed quantitively (speed) and not qualitatively.

Gompel *et al*., (2004)	Children with a vision impairment rely more on sentence context and demonstrated the same reading ability as normally sighted readers – just slower.

Table 2.5. Summary of main reading measures including: **Reading Reserve**: ratio of critical print size to smallest font size read. **Crowding Extent**: ratio of crowded acuity to uncrowded acuity.

2.4 Discussion of the Systematic Review findings

The aim of this systematic review was to evaluate the literature surrounding the impact of childhood VI on academic performance. The evidence surrounding this area was scarce, with articles reviewed focussing on the impact VI has on reading performance primarily. The included studies all achieved a quality score of over 70% using the CASP checklists. Despite an inability to perform a meta-analysis of the results owing to different outcome measures and methodological differences between the studies, this systematic review highlighted the reduced reading and literacy skills between students with a VI and their normally sighted peers. All seven included studies analysed reading ability and reported that children with a VI read at a slower rate than their normally sighted peers. One reason proposed to account for this difference was that VI children were exposed to less incidental reading such as reading timetables or road signs than their normally sighted peers. Reading advertisements and notices in shop windows, on buses or trams and reading road signs are just a few of the many ways that reading is reinforced and practiced in normally sighted children. Bosman *et al.*, (2006) found that VI children employed the same phonetical learning strategies as a normally sighted children, but the children with VI were limited by the practice that was taken for granted during incidental reading of a child with normal vision.

Literacy skills have been shown to be a good indicator of future academic performance (Butler *et al.*, 1985; Stevenson and Newman, 1986) and early literacy (and competency in mathematics) begins its development in early childhood prior to formal education. These early literacy skills, developed before a child begins school, have been shown to be important factors in the development of reading ability (Purpura *et al.*, 2011). The lack of early, incidental practice for children with VI results in reduced development of these early literacy skills which may contribute to the gap in reading speed ability between children with normal sight and those with a VI.

MacDonald *et al*., (2012) evaluated a group of children and adults with albinism to determine whether their VI impacted the development of reading skills. Although they observed that reading speed was slower, they found comprehension skills were normal. Indicating that VI with normal cognitive ability, does not impact the acquisition of normal reading skills.

Typically, the educational support for a child with a VI is determined by their distance VA which may not be a suitable of near vision performance when most classroom visual tasks require good near vision (Narayanasamy *et al*., 2016). Determining the optimal print size for reading is therefore essential to maintain engagement in classroom learning throughout the day. Lueck *et al.*, (2003) found that when print size was not optimal there was a significant drop in reading speed. Huurneman *et al*., (2016a) investigated the difference in these characteristics between children with albinism and infantile nystagmus, finding that reading acuity was worse in children with albinism than infantile nystagmus - even after accounting for VA measures. They also found children with a larger crowding extent (the difference between crowded and uncrowded acuities), required a larger critical print size (CPS) as crowding effected letter and word recognition.

Corn *et al*., (2002) demonstrated a significant increase in reading speeds in years 1-3 of school following the use of an optimal optical device over a four-month period, which highlighted the importance of improving accessibility to reading materials during early primary years. Older students did not show the same degree of improvement when using the same intervention, illustrating the importance of early intervention to improve accessibility to reading material at an earlier age during the 'learning to read' process. However, the study did not consider any support or specialist training the students may have received over this four-month period. The study authors acknowledged that some of the students did have specialist vision support teachers which may have impacted the findings.

Focus groups of children with a VI report a dislike of reading (Khadka *et al*., 2012), perhaps because this particular near visual task is challenging and requires extra effort, possibly resulting in additional visual fatigue and tiredness (Schakel *et al*., 2019). This reluctance to read beyond requirements, in contrast to normally sighted children, presumably also limits any recreational reading at home and adds to the lack of reading practice children with a VI undertake outside of the classroom. Khadka *et al.*, (2012) also identified a voiced need for children with a VI to be independent and felt, at times, limited in this independence by parents and support teachers. Accentuating a need for support based around independent accessibility and the need for children with a VI to develop their independence skills that can be used for education and beyond. A recent systematic review of the factors relating to employment outcomes of students with a VI found that education level had a positive effect on employment level and future earnings of VI students, emphasising the necessity of optimal education for improved future outcomes (Lund and Cmar, 2019).

This systematic review indicated that there was a generalised lag in the reading ability of students with a VI compared with their normally sighted peers in terms of reading speed. Despite this there remains no definitive criteria for support based on VA that was acknowledged and accepted worldwide. Many countries have systems for support within classrooms and some countries have specialist VI teacher training centres to enhance support within the classroom. Often though, this task is left to a classroom teacher, who may have limited knowledge of VI and its implications on a child's visual function and their limitations within the classroom learning environment.

For example, teachers may not be aware of the significant visual fatigue during a school day within a classroom environment, which can manifest in different ways, such as headaches and tiredness experienced by children with a VI, that may manifest as negative changes in behaviour during the day (Schakel *et al.*, 2019). Teachers may then struggle to determine if, or what, aspects are due to the child's VI or other extrinsic factors such as bullying. Primary educators may not have adequate experience of VI and can be faced with the difficult task of translating a VA result or visual field analysis into a functional measure of the child's vision performance in class. Distance VA is a measure of the eyes resolving ability and does not provide comprehensive knowledge around functional visual ability to enable adequate support within a classroom environment that is dominated by near tasks. Reading, writing, and literacy skills are essential foundations that are crucial for education, and the ability to achieve optimal educational outcomes is inherently determined by the ability to master these basic building blocks to learning. Strong literacy skills have been found to have a significant impact on future academic achievement (Butler *et al*, 1985; Purpura *et al*., 2011), and literacy and mathematical ability have been shown to be related over time with a difficulty in one area often associated with difficulty in another (Purpura *et al*., 2011).

The systematic review was limited by restricting studies to those in English only which may have resulted in studies of other languages being excluded. The included studies also utilised several different methods for measurement of VA and analysis of reading. These differing outcome measures resulted in the inability to draw direct comparisons across studies and perform a meta-analysis of reading performance and VA. Two studies did not specify VA measures but were included due to a diagnosis of VI, which may have biased some of the study results. As participant recruitment was either from specialist VI schools or mainstream schools, the students from specialist schools may have received more specialist vision support within the classroom which may have additionally biased results obtained.

2.2.6 Conclusions

The evidence surrounding educational outcomes for VI children is limited by the level of available studies. The inability to synthesise results makes it difficult to form a quantitative appraisal of the current literature and a definitive answer to this review question. Although the studies included in the review indicate that reading and literacy skills for VI students lag their normally sighted peers in terms of reading speed, a comprehensive longitudinal study would provide more substantial evidence and inform educators surrounding areas of need.

Future studies could look more broadly at VI and the impact this has on standardised measures of reading performance using the same near tasks then categorising childhood VI based on functional ability. A case report described in detail in **Chapter 5** further highlights the improvements in reading performance possible following a functional vision assessment (Loh *et al*., 2022). This form of assessment should be enabled at an early age to develop early literacy skills, encourage independent accessibility skills, and build the foundations required for continuing education or employment (Corn *et al*., 2002). More studies are required in this field to assess the most appropriate tests and interventions for children with a VI to improve their outcomes. Many studies have focussed on acquired VI later in life secondary to stroke (Rowe *et al*., 2011), age related macular degeneration (Kwon and Owsley, 2023) and glaucoma (Nguyen *et al*., 2014) and similar attention should be given to VI in early childhood and its impact on education.

2.5 Summary and relevance to Research Questions

Students with a VI face unique challenges within the classroom environment, and the speed at which they can access educational information can significantly impact their learning experience. This systematic review has revealed that students with a VI use the same strategies for learning but are limited by the speed at which they access information. The ability to individually assess students functional vision capabilities, identify deficits or areas of difficulty, and provide strategies aimed at targeting these specific areas would provide enhanced support within the classroom environment and enable a more inclusive educational experience for these students.

CHAPTER 3 : METHODS

This chapter details the inclusion and exclusion criteria of students with VI. This chapter also includes details of the tests of functional vision and visual function performed and the rationale for these tests.

3.1 Participants

All students with a VI supported within the South Australian School and Services for Vision Impaired (SASSVI) are assigned a specialist vision support teacher. This teacher performs regular visits to the student at their own school to assist the class teacher and school with any support the student may need in terms of adjustments to the classroom environment or learning materials.

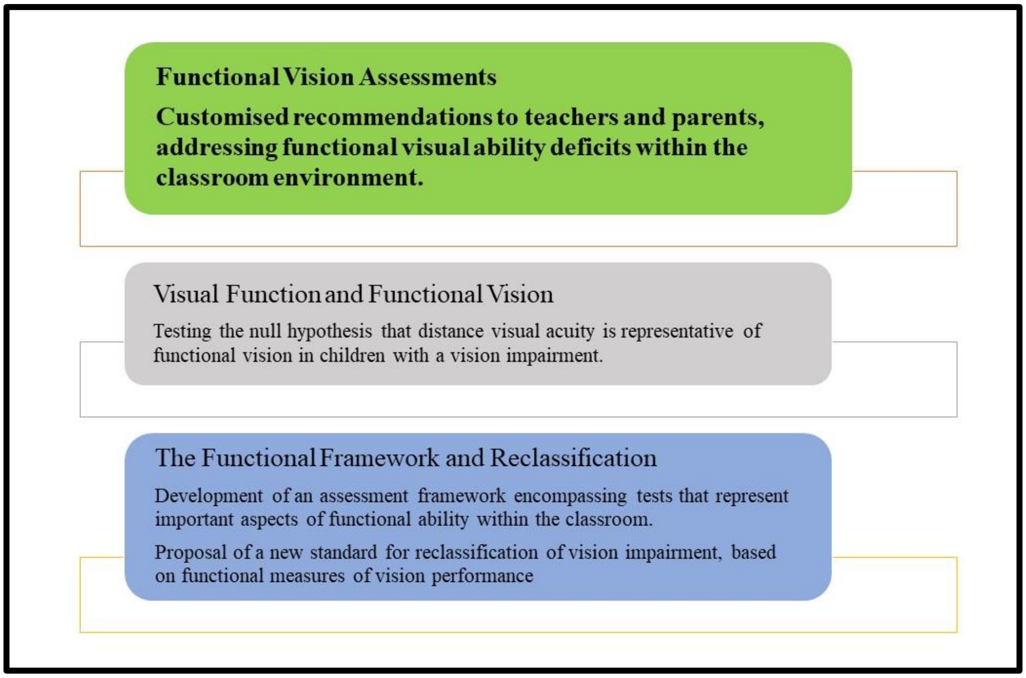
VI participants were all recruited through SASSVI. Students supported by SASSVI all met inclusion criteria as having a VI as confirmed by an ophthalmologist. It was anticipated that approximately 150 children would enrol in the study over an 18-month period between June 2020 and December 2021. Discussions with teachers at SASSVI were provided to outline the details of the intended study design, which was to assess various measures of functional vision and provide information to the support teachers to implement accommodations aimed at improving the student's accessibility to the curriculum within the classroom. Following the information sessions, participant information sheets for the parent/carer and child were sent by the school to prospective participants.

Participants were excluded if they had a neurodevelopmental disorder such as autism spectrum disorder, additional learning disabilities indicated by intellectual disability, or profound hearing loss.

Eligibility based on VA was by previous enrolment in the statewide support system where inclusion criteria was required to be met. To be eligible for support within the statewide support system, a student must have been previously diagnosed with a pathological VI by an ophthalmologist, and their VA and/or visual field extent meet eligibility criteria (VA of 6/18 (0.50 logMAR) or less in the better eye and/or restricted visual field (SASSVI, 2023). Participants were aged between 5 to 18 years and in full-time education. Appropriate refractive correction was worn for all vision assessment tasks if required.

Following the functional vision assessment, a comprehensive report including advice and recommendations to improve performance was provided to the participant, their parents, and teachers that detailed any functional deficits that were revealed during the assessment (See **Chapter 5.2.1** and/or **Appendix 9** for examples).

Functional Vision Assessments



Functional Vision Assessments followed by customised recommendations to teachers and parents, addressing functional visual ability deficits within the classroom environment.

Functional vision assessments are an assessment of how well the individual can perform a visually guided task such as reading, or copying a figure, or finding a word hidden in text, and represent real world activities that may be encountered in the classroom.

Functional vision assessments were performed at varying schools across South Australia. The majority took place at a SASSVI School, but this was not always possible and often dependant on the student and parents' ability to travel. If a student was unable to travel, the assessment was performed within the students' mainstream school.

To enable optimum communication and support amongst the students' care team, it was encouraged that the primary caregiver, the class teacher, and their vision support teacher was present at the functional vision assessment. This allowed the primary care team to observe firsthand the student's ability to perform the visually guided tasks that formed the basis of the functional vision assessment. Having the parent and teacher present, further enabled a full and comprehensive history, including difficulties encountered both at school and at home, due to their VI.

Following the functional vision assessment, time was taken to have a discussion around the student's visual ability. This conversation, which was student centred, enabled communication of the student's functional vision capabilities and limitations. Recommendations and advice surrounding optimising their visual performance within the classroom were then discussed, with strategies aimed at addressing any limitations to maximise independent accessibility within the classroom for the student.

To develop a functional vision assessment framework that had the potential to be used on a large scale to support students with a VI, it was necessary to identify a suite of tests that were readily available and could be performed by any healthcare professional and still provide an evaluation of functional vision.

The availability of equipment, cost, size, and transportability factored in the selection of the appropriate tests. The capacity to allow for assessments to be performed at varying locations was also a practical consideration that guided the choice of equipment that could perform the functional vision assessments in different testing environments. The tests and equipment were also selected with consideration of participants and their ease of use and their applicability for the age range of the participants from primary to secondary school.

3.2 Vision Function Tests

These tests were standard clinical measures of visual function and justification for the specific test and its inclusion are detailed below. Tests included: :

- VA (crowded and uncrowded acuity)
- Contrast sensitivity
- Cover test
- Ocular motility
- Vergence
- Visual electrophysiology
- Visual fields

3.2.1 Visual Acuity

VA was the main outcome measure with which to compare the functional visual tests. It was necessary to find a VA test that best met the following criteria:

1. Suitable to use with all ages from 5 to 18 years.
2. Could be portable and suitable to be used in different locations.
3. Quick and easy to administer.
4. Provided a reliable and consistent measure of VA across a range of VAs from 6/5 to NLP (-0.05 to 3.0 logMAR).

Several test charts were considered, including the Snellen letter chart, LogMAR and the computer-based Freiburg Acuity Test (FrACT) (Bach, 1996; 2007). It has also been shown that there is no clinically significant difference between the VA measures found on FrACT, compared with logMAR charts (Schulze-Bonsel *et al.*, 2006). However, the logMAR and Snellen chart were excluded in preference for the FrACT. This was because the FrACT was able to generate Landolt Cs in a wider VA range and used a best Parameter Estimation by Sequential Testing (best PEST) testing strategy to staircase to the psychophysical limit of VA which was not available with traditional tests charts such as Snellen or logMAR charts. Best PEST determines the VA threshold based on previous responses. The algorithm works on a logVA scale, adjusting step sizes to accommodate the logarithmic progression of VA. Initially, step sizes are relatively large (about 3 lines), but they decrease to less than 1 line as the algorithm narrows down the VA threshold. This approach leads to more presentations of optotypes near the subjects VA threshold. Additionally, the Landolt C size and orientation vary with each trial, being fully randomised. The best PEST program algorithm determines the most likely estimate of the threshold, given the optotype grades and responses so far, and then presents the optotype exactly at the current threshold estimate, thus maximising information gain. FrACT is also independent of lighting requirements which was an important factor as assessments were performed in different locations and constant illumination levels could not be maintained.

The Freiburg Vision Test was chosen as the most suitable test that best met the criteria required to assess VA in students with VI.

Distance Visual Acuity: Freiburg Vision Test 'FrACT'

The **FrACT** is a computerised visual acuity testing procedure that utilizes a Landolt C (Bach, 1996; 2007) as shown in **Figure 3.1**. The most familiar test of VA utilises letters on a chart, either a logMAR or a Snellen, which are comprised of letters in gradually reducing size to determine minimum resolution. To achieve 6/6 (0 logMAR) VA an observer would need to resolve a letter which subtends 5 minutes of arc at the eye. A Landolt C utilises the same concept with a 6/6 Landolt C subtending 5 minutes of arc, with the observer required to indicate the direction of the gap in the letter C (orientation), which is 1 minute of arc wide.

Figure 3.1: FrACT

Figure 3.1. The Landolt C display with customised keypad input device for use by the study participants. The Freiburg Acuity Test (FrACT) met the criteria necessary, being portable, reliable, and easy to use across the age and visual acuity levels of the participants. The participant would depress the up/down or left/right arrow key to indicate the direction/location of the 'gap' in the Landolt C. The Best PEST procedure built into the FrACT program staircases to the psychophysical threshold for resolution of the gap using a four alternative forced choice paradigm (Bach, 1996; 2007).

To measure VA with the FrACT, a Landolt C is presented on a computer monitor and the participant was required to indicate the orientation in the gap of the letter C by responding to four forced-choice alternatives (the subject is forced to respond even if they are unable to confidently determine the gap by taking a “best guess”). This was performed either by the participant saying the direction of the gap - right, left, up or down, or by utilising the purpose-built keypad which could be pressed to indicate the orientation of the gap. This keypad was built for simplicity and unnecessary keys covered in black, with the four alternative choices marked by large print, high contrast arrow labels as shown in **Figure 3.1**. For younger participants or those that were reluctant to verbalise the orientation, a large, printed letter C was provided, if required, that the participant could turn to the same direction as the C on the monitor. The use of Landolt C for the VA testing enabled the use of an identical chart for all age groups, because not all the youngest participants knew all the letters of the alphabet. FrACT allowed for this multisystem approach for responses which increased engagement with student responses, particularly in students who were less confident. This resulted in the VA test being suitable for all age groups. The ability to perform at a shorter working distance was also beneficial for the testing of younger children with a VI and students with very low VA (1.52 logMAR (6/200)) .

Procedure

Prior to commencement of the test, the MacBook screen required calibration for the testing distance and screen resolution so that the number of pixels on the screen equated to a MAR of one. These were inputted in the “settings” screen, the testing distance was measured as screen to eye in centimetres, screen calibration to MAR was determined by measuring the length of a standard blue line in the settings screen and inputting the measurement in millimetres based on the screen size and the pixel resolution.

Although FrACT can display a Landolt C in 8 different orientations; left, right, up and down, and 4 oblique presentations between these, for this study 4 orientations were used (up, down, left, and right). This allowed the test to be less confusing for younger participants and those with a VI. The program automatically adjusted the parameters of the test when the four alternative forced choice option was selected and increased the number of trial presentations until threshold VA was reached (Bach, 1996). FrACT presents the Landolt C orientation randomly, therefore eliminating the ability to predict or memorise the correct responses which is possible with a traditional letter chart with fixed letters on each row.

In the "settings" screen the optotype presentation can be changed to either an uncrowded or a crowded Landolt C by adding a frame, flanking rings, or flanking optotypes. Where possible both crowded and uncrowded acuity were measured. A crowding frame was used to measure crowded acuity and where it was not possible to determine both uncrowded and crowded acuity, binocular crowded VA was measured as depicted in **Figure 3.2**.

Figure 3.2: Uncrowded and Crowded Landolt C

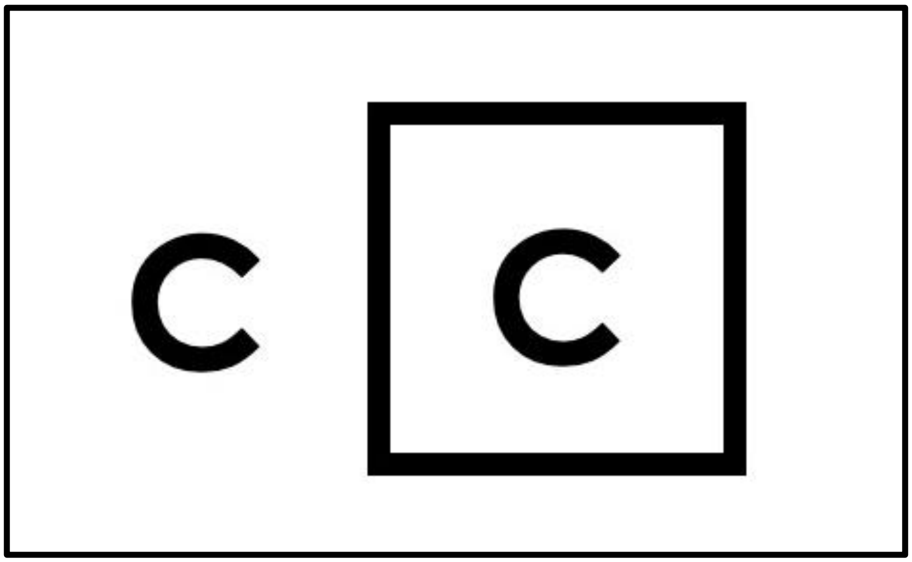


Figure 3.2. An uncrowded Landolt C, and a crowded Landolt C surrounded by the flanking or crowding box at a spacing of twice the limb (gap) of the Landolt C.

One advantage of using the laptop screen to assess VA was that the laptop could be used at different testing distances to accommodate the different test locations and needs of the participant if they had low VA. The testing distance was input before commencement of each test and was measured with a metal measuring tape. The participant's viewing distance was monitored during the test to maintain a constant test distance during the VA trials. The display luminance was unaffected by room illumination levels which were kept low and ranged from 300-400 lux as measured with a smartphone LighterMeter Application before each trial began.

A Landolt C was presented first, and their size was reduced using the best-PEST algorithm. Using best PEST adaptive-staircase step procedure, Landolt C presentation size steps are initially large, but become smaller nearer to the VA threshold. Results from the test were calculated based on the testing distances and presented in logMAR on an output screen at the end of the test.

Most of the participants were tested at one metre, unless they had very low vision, and then the testing distance was reduced to fifty centimetres and the settings adjusted to reflect the change in testing distance.

The FrACT can also quantify VA in the lower range, which has previously only been given a semi-quantitative clinical scale of count fingers or hand movements (Schulze-Bonsel *et al*., 2006). These semi-quantitative measures are considered inaccurate as they are dependent on testing conditions and contrast - a hand against a light background (e.g., white coat or wall) has a much lower contrast and is harder to see than a hand against a dark shirt for example. The difference between the semi-quantitative measures of count fingers and hand movements can be greater than 4.5 lines on a logMAR chart (Schulze-Bonsel *et al*., 2006), this large difference in measures would be significant from a functional perspective as students with a VA of count fingers would likely be able to identify large letters and have superior functional vision than a student with hand movements. FrACT can record these measures in a LogMAR scale (up to NLP of 3.0 logMAR), giving a more accurate measure of the difference between these two measures. The output also provides a quantitative measure that was psychophysically obtained and could be used more readily in the analyses, being bias free due to the participant correctly guessing a letter or 'giving up' early on a test.

Landolt C is a measure of resolution acuity rather than recognition acuity i.e., letter charts. Although it would be intuitive to assume that the measure of recognition acuity would be a more valuable measure of a student's performance in a classroom, two studies comparing VA results from FrACT and logMAR charts, found that VA measures were within 0.05 logMAR (Pointer, 2008). Since there are no clinically significant differences between the two different VA measures, the benefits of using FrACT (portability, testing distance, child engagement and the ability to quantify lower levels of VA more accurately) made it the most appropriate VA test for the VI study population.

3.2.2 Contrast Sensitivity

Contrast sensitivity is the ability to detect an object against its background. A high contrast task would be black on white, compared to a lower contrast task, for example grey print on a white background (Pelli and Bex, 2013). Contrast sensitivity is an important indicator of visual ability and performance in those with a VI and can impact their visual performance and reading speed (Brussee *et al*., 2017; Giacomelli *et al*., 2010). Contrast sensitivity in the VI group was important to measure because of its dependence on illumination and the clarity of the optical media, which if poor, will reduce retinal illumination and degrade contrast sensitivity (Liu *et al*., 2017). The contrast of text can be improved with electronic devices that can provide higher contrast and larger font size than is typically available with printed material and have proved successful in increasing reading speeds in subjects with age related macular degeneration (Gill *et al.*, 2013).

Contrast acuity was measured using the FrACT Contrast C protocol. For this test, the size of the Landolt C was kept constant, and the Weber contrast reduced until threshold was reached using the four alternative forced choice method. **Figure 3.3** illustrates the test with a Landolt C's orientation changing with different levels of contrast until the participant was unable to resolve the gap in the Landolt C.

Figure 3.3. The Frieburg Acuity Test Contrast C

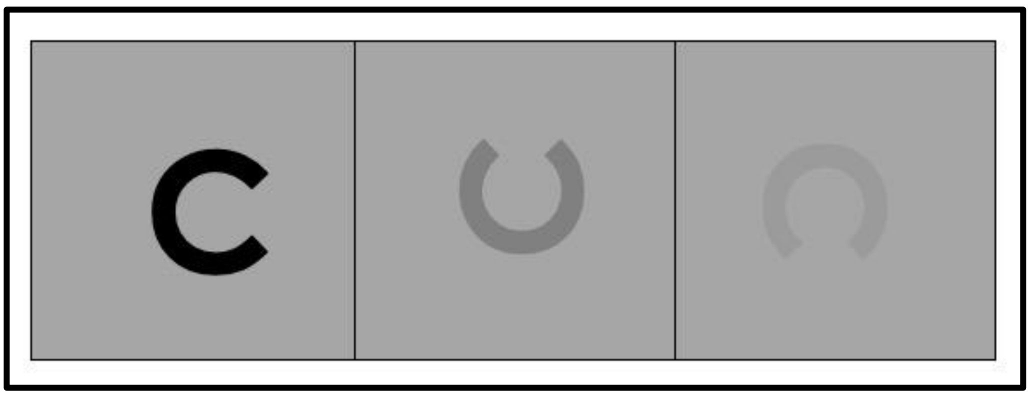


Figure 3.3. The Freiburg Acuity contrast C test presents a fixed size Landolt C in one of 4 orientations. The contrast between the C and background is reduced until the participant is unable to resolve the location of the gap in the C. The low contrast (logCS) at which this occurs is the threshold contrast sensitivity. All measurements used Weber contrast.

The initial Landolt C test size for each participant was based on the individual's baseline resolution VA at high contrast and adding 3 x their acuity reserve (FrACT contrast C test size = resolution high contrast acuity x 3). This ensured that each participant's test size was scaled to their baseline resolution acuity and was based on the Pelli-Robson Contrast Sensitivity test cards that utilise 0.50 logMAR (6/18) optotype letters at a testing distance of 1 metre for individuals with 'normal' 0.0 logMAR (6/6) VA.

Identical to the FrACT VA task, the standard test distance was one metre, unless the participants had very low vision and were unable to resolve the largest Landolt C at this distance, then the test distance was reduced to fifty centimetres and the settings adjusted to reflect the change in testing distance. Participants used the same method to indicate the orientation of the gap in the Landolt C as they had used in VA measurements as shown in **Figure 3.1**.

Tests of Binocular Function

3.2.3 Cover Test

Eye alignment was assessed using a unilateral and alternate cover test to detect the presence of strabismus or phoria.

A standard cover test was performed for near using an appropriately sized accommodative target - dependant on VA. The participant sat directly opposite and was directed to look at the near accommodative task at 40cm. This was performed with the participant's refractive correction if one was required for near work.

Participants who were unable to perform a cover test adequately for reasons such as very low vision or fixation difficulty underwent the Hirschberg test, or the corneal light reflex test, to detect the presence of a strabismus.

A cover test was performed to provide practical advice to teachers on their students's visual function within the classroom and was not used for data analysis. Examples of advice given are in appendix 9.

3.2.4 Ocular Motility

Binocular ocular movement assessment was used to evaluate oculomotor control and the potential impact this may have on being able to function in the classroom when engaged in visual search tasks or reading. Most of the VI group had poor ocular motor control that in some cases was made worse by the presence of nystagmus.

Binocular eye movements were assessed with the participant sitting directly opposite the observer who instructed the participant to follow a target (usually a light unless they were very light sensitive and then a non-illuminated target was used (such as a pencil with a coloured top) from the primary position of gaze to the six cardinal positions of gaze using an H pattern. Any restriction in movement in any of the six gaze positions was noted if present, and the presence of jerky pursuits were noted. The presence of any nystagmus was also observed and recorded for each participant as present or absent in the primary gaze position only.

Ocular motility was performed to provide practical advice to teachers on their student's visual function within the classroom and was not used for data analysis. Examples of advice given are in appendix 9.

3.2.5 Vergence

To assess convergence ability, near point of convergence was measured. The participant sat directly opposite the observer and was instructed to fixate on an appropriately sized accommodative target (the same target used for cover test) at 50cm. The target was then brought slowly towards the participants' nose, and the convergent eye movements observed to detect when either eye 'broke' when convergence was lost, or if the participant reported that the target became double. The distance at either of these points was measured with a metal tape and recorded as the Near Point of Convergence (NPC) in centimeters. If a reduced NPC (less than 10cm) was noted, a jump convergence test was performed to determine if the reduced NPC might impact functional performance, as jump convergence is often associated with symptoms of asthenopia (Pickwell and Hampshire, 1981). To evaluate jump convergence the participant was asked to "jump" fixation from the near accommodative task at 15cm to a small distance target at 3m, such as a letter on a wall. The participant's eyes were observed as they changed fixation from the near to distance target and the observer noted if there were any slow or hesitant movements of the eyes or an unequal or inaccurate movement of either eye.

Vergence was performed to provide practical advice to teachers on their student's visual function within the classroom and was not used for data analysis. Examples of advice given are in appendix 9.

3.2.6 Visual Electrophysiology

Electrophysiology is a standard clinical assessment when investigating a student with a vision impairment to determine retinal function, particularly in students with retinal dystrophies. Clinical visual electrophysiology consists of a series of tests performed under dark and light adapted conditions to assess retinal and macular function. Depending on the state of retinal adaption, the stimulus intensity (flash strength), colour and flash duration or pattern the electrical signal of the retina can be recorded to aid in the diagnosis of retinal and visual pathway disorders (Robson *et al*., 2018). The visual electrophysiological test chosen for this study was the 30Hz light adapted flicker test that assesses specifically the function of the L and M cone pathways of the retina (Robson *et al*., 2022). The 30Hz flicker was chosen because of its short test time and high signal to noise ratio and is used to evaluate inner retinal dysfunction in diabetes and so is a sensitive test for light adapted retinal function (Maa *et al*., 2016).

The electroretinogram (ERG) is the recorded waveform of the underlying neural generators of the retina in response to a flash of light. The International Society for Clinical Electrophysiology of Vision (ISCEV) makes recommendations about the standard recording of the ERG (Robson *et al*., 2022) that are typically updated every five years. Generally, the ERG waveform consists of an initial negative a-wave that is due to the hyperpolarisation of the photoreceptors (Robson *et al*., 2003). The following positive b-wave is the result of depolarisation of second order bipolar cells with high frequency oscillatory potentials seen on the rising limb of the b-wave that originate from the amacrine cells (Dang *et al*., 2013; Wachtmeister, 1988) **Figure 3.4** illustrates the ISCEV standard light- and dark-adapted ERG waveforms recorded from the right eye of a normal observer aged 14 years of age.

Figure 3.4: ISCEV standard ERG waveforms

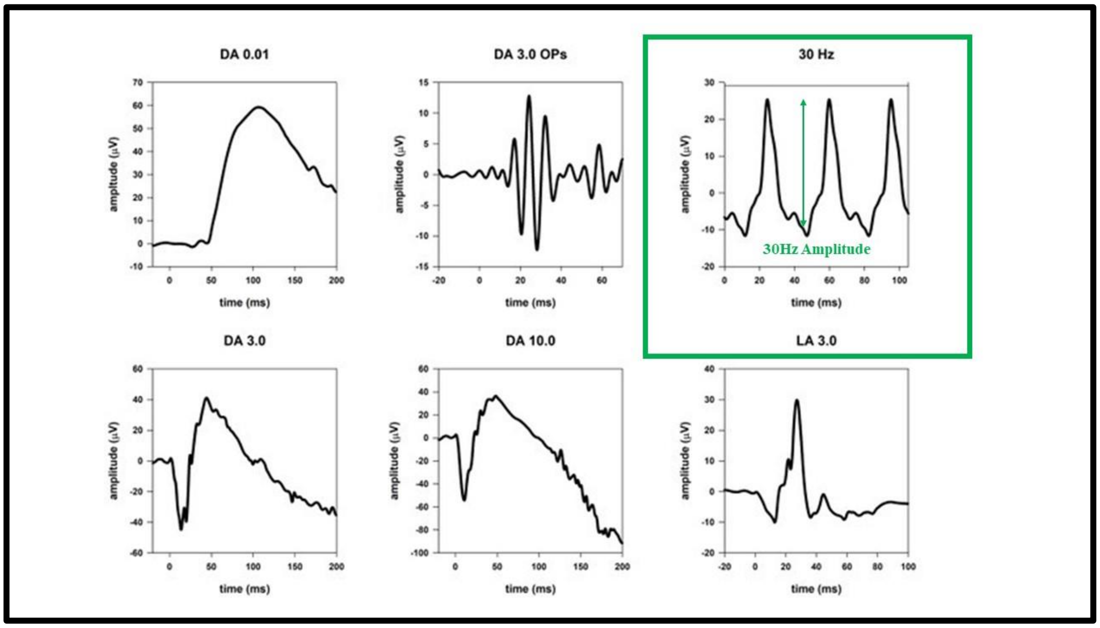


Figure 3.4. Panel illustrating the ISCEV standard ERG waveforms under dark (DA) and light adapted (LA) conditions. The DA0.01 is the dark-adapted pure rod and rod bipolar cell response. The DA3.0 and DA10.0 are dark adapted responses to 3 and 10 cd.s/m^2 brief white flashes and illustrate the initial negative a-wave followed by the positive b-wave. The DA3.0 OPs are the oscillatory potentials that are filtered responses from the b-wave and originate in the inner retina. The LA3.0 is the light adapted cone driven response and the 30Hz flicker is the LA response of cone driven retinal neural pathways from the L and M cones and represents the functional integrity of these pathways. The 30Hz waveform is highlighted in the green box with the 30Hz amplitude shown as the peak to trough amplitude of the steady state retinal response.

Recording the 30Hz flicker electroretinogram

The RETeval (LKC Technologies Inc, Gaithersburg, MD, USA) is a portable handheld ERG device shown in **Figure 3.5**. The RETeval is less invasive and more comfortable for use with children because it does not require pupil dilatation when using the Troland based protocols and the use of sticker electrodes, placed below the eye, are typically more comfortable than traditional fibre or gold foil electrodes that contact the surface of the eye (Zhang *et al*., 2021).

The self-adhesive skin electrodes were positioned 2 mm below the lower lid in accordance with the manufacturer's recommendations as shown in **Figure 3.6**. Retinal cone function was assessed using a full field light adapted 30Hz flicker ERG. The right eye was always recorded first. The white flash of stimulus strength of 32 Td.s (equivalent to 3 cd.s/m^2 in a 6 mm pupil) was used with zero background luminance. Responses were averaged and filtered 0.1-300Hz to obtain the average waveform Artefact rejection was in built with any waveforms rejected if they fell outside 2 SD of the mean. The 30Hz steady state amplitude and the peak-to-peak times were exported from the average traces for each eye.

Figure 3.5: Electroretinogram recording

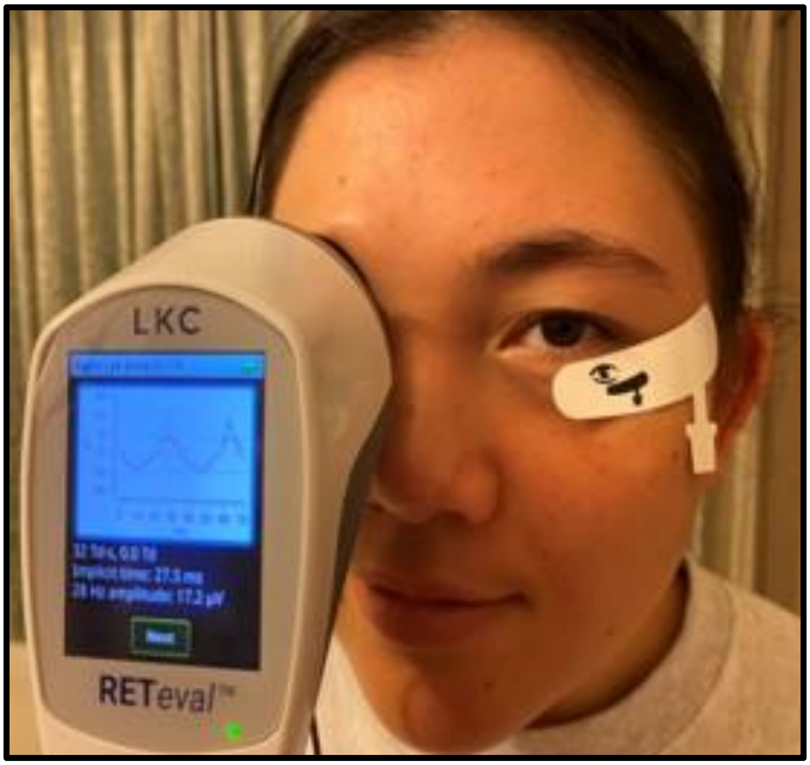


Figure 3.5. The RETeval handheld electroretinogram recording device with skin electrodes positioned below lower lid recording the 30Hz flicker response and reporting peak to peak time of 27.5ms with an amplitude of 17.2 µV.

3.2.7 Visual Fields

Although support criteria for students with a VI can be based on visual field extent, this was not quantified during the assessments. The reasons for this were in part the limitations on time and the quality of the visual fields obtainable in the VI population. Since the equipment required needed to be portable, the use of the Melbourne Rapid Field test (Kong *et al*., 2016) running on an iPad was trialed on two normal observers. However, it was considered that the visual field assessment took too long (>5 minutes) and many of the participants had nystagmus, affecting their ability to maintain fixation and perform the visual field test without a high number of fixation losses. As an alternative, where possible confrontation testing was performed to identify any substantive quadrant or hemifield absolute defects.

Confrontation fields were performed to provide practical advice to teachers on their student's visual function within the classroom and was not used for data analysis. Students were referred to their optometrist or ophthalmologist if further field testing was deemed necessary. Examples of advice given are in appendix 9.

3.3 Functional Vision Assessment Tests

3.3.1 Reading Performance

All reading analyses were performed using the MNREAD Application 2017 (Calabrèse *et al*., 2018). The MNREAD Application was developed at the Minnesota Laboratory for Low-Vision Research at the University of Minnesota (Calabrèse *et al*., 2018; Legge *et al*., 1989) It has been extensively tested and is available in multiple languages worldwide (Idil *et al*., 2011; Mansfield *et a*l., 2019; Mataftsi *et al*., 2013; Merrill *et al*., 2011; Virgili *et al*., 2004a; 2004b). The MNREAD has been evaluated in 165 normal and 45 VI observers to compare measures of maximum reading speed between the iPad digital screen and printed material and was not significantly different in the VI group supporting its use as a measure of reading speed for the study population (Calabrèse *et al*., 2018).

MNREAD was developed to assess aspects of reading, such as reading acuity (smallest print size that can be read without significant errors), critical print size (CPS) (the smallest font size read at maximum speed), accessibility to printed material and maximum reading speed (maximum reading speed not limited by print size). It uses standardised text at each logMAR font level. At each font size presented there are the same number of letters or words and the spacing is proportional to the print size. The progression reducing print size follows a constant ratio with each successive sentence of words decreasing by 0.1 logMAR units.

Reading analysis can be performed for both normal polarity (NP) (black text on white background) and reverse polarity (RP) (white text on black background) as shown in **Figure 3.6**. All reading performance measures were tested under NP and RP conditions. The test distance was input before testing for each participant depending on their VA. Typically this was 40cm but in cases of very low VA the reading distance was reduced to 10cm.

The students used for data analysis all had proficient reading skills. The MNREAD is designed to assess reading from approximately 8 years old. However, some of the students were proficient readers at ages younger than this.

The decision to use a student for data analysis was determined following the reading assessment and was decided by the specialist vision support teacher who indicated their reading level. If it was felt that the student was below this level, then they were excluded from data analysis.

Figure 3.6: iPad sentence display sequence from MNREAD

Figure 3.6. A sample of print displayed on the iPad running the MNREAD program. On the left normal polarity text and the right reverse polarity text. The text displayed decreases by 0.1 logMAR and continues to reduce in size until the participant is no longer able to read the text aloud with fewer than 10 errors. An example of 'an error' was a missed, or a mis-read word.

The MNREAD program displays a single sentence in the centre of the screen at the tap of a finger, which also starts the timer. Each sentence contains sixty characters and is composed of common words found in year two and year three reading materials. The participant was asked to read the sentence aloud, as quickly and as accurately as possible. Once read, a finger tap on the screen stopped the timer and a score screen was displayed with time taken to read the sentence. Additional sentences were then displayed at reducing print sizes until the participant could no longer read the text, or the participant made ten or more errors. **Figure 3.7** shows the typical sentence displays from start to finish. Each participant was encouraged to read even when print size was difficult and to stop only when print was too small to read. The reading distance was measured using a metal ruler before each trial and was monitored throughout reading until completion by the examiner. The output of the MNREAD displays the performance measures for reading acuity, CPS in logMAR and maximum reading speed in WPM.

Figure 3.7: iPad sentence display sequence from MNREAD.

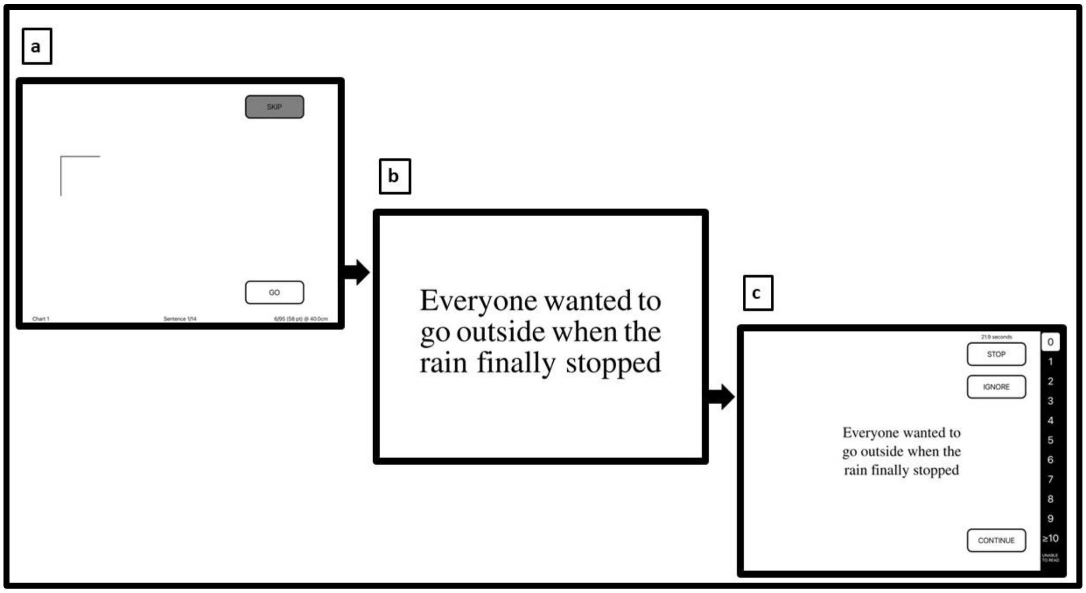


Figure 3.7. Initial start screen with bracket indicating position of where the sentence will start/appear (a), sentence screen (b), and screen display (c) after the sentence is read and the timer stops. Screen 'c' notes the time taken to read the sentence in seconds and allows for any errors in reading to be recorded on the side panel. Figure modified from Calabrèse *et al*., (2018).

Reading Performance Measures

Critical Print Size (CPS) is the largest font size before reading speed begins to decrease and is defined as the print size at which subsequent smaller print sizes were read at 1.96 SD slower than the mean of the preceding print sizes.

Font size and reading speed are intrinsically linked - if too large a font size is read for VA levels, then reading speed is slower due to a reduced number of words on a page and the individual needs to scan more which takes more time. As font size reduces, reading speed increases until a maximum reading speed (MRS) is reached and remains relatively constant across several smaller font sizes. However, as the resolutions limits are neared with gradually reducing font sizes, the MRS slope falls sharply until the absolute resolution limits are reached and the individual is unable to resolve the font to continue reading. **Figure 3.8** illustrates the changes in MRS with reducing font size and the CPS where the MRS falls sharply.

Figure 3.8: Maximum Reading Speed and Font size

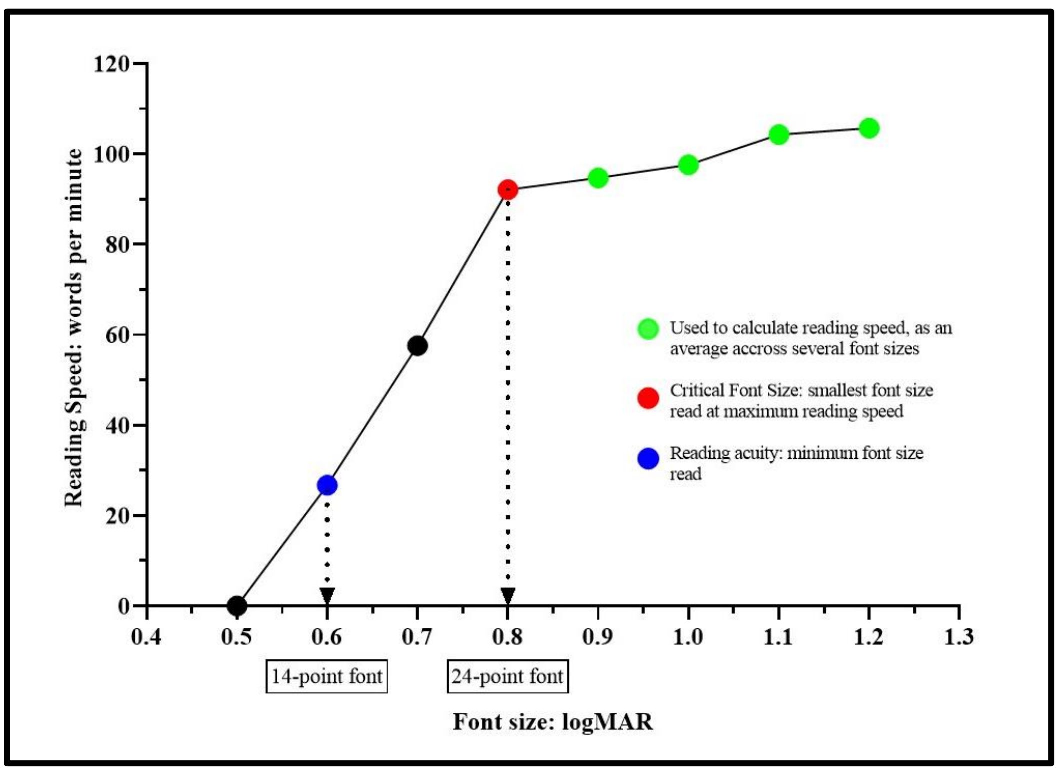


Figure 3.8. Typical reading speed changes with font size for a participant with a vision impairment. The red circle indicates the Critical Print Size, which is the point at where reading speed starts to reduce and is the optimal font size required so that reading is achievable at the

fastest speed with the minimum font size. The green circles show how reading speed remains relatively constant across several font sizes and are used to calculate maximum reading speed. The blue circle indicates the smallest font size read. Reading distance was at 40cm in this example.

Neale Analysis of Reading Ability

The Neale Analysis of Reading Ability (NARA) (Douglas *et al*., 2002) was considered as a possible alternative to the MNREAD. The NARA is reading ability assessment suitable for students aged six to twelve years. It consists of six passages of text with increasing difficulty which a student is required to read aloud. Performance level is graded by reading ages for accuracy, comprehension, and speed.

Since reading performance for students with a VI was required to assess functional vision in terms of print size requirements and reading speed, this test was deemed less appropriate. Although the NARA can determine reading speed, the focus of this reading analysis is on comprehension and understanding of text, whereas MNREAD assessed reading performance in terms of vision. Although it would have been useful to also measure comprehension, neither of the two tests assessed all reading metrics (MRS, CPS and minimum font size) in addition to comprehension. NARA also required a significantly longer test time, which would have made the overall functional vision assessment longer and potentially reduced engagement with the tasks due to fatigue.

3.3.2 Visual Processing

Test of Visual Analysis

The Test of Visual Analysis (TVAS) requires the participant to accurately visualise and reproduce a line drawing. This task is an example of visual motor integration which is the capacity to combine motor skills with the visual information to execute a task such as drawing (Sepulcre, 2014). A component of visual processing that is crucial for early learning is visual analysis (Simons, 1993), and visual motor integration is essential in a classroom for tasks such as learning to write (Capellini *et al*., 2017). Visual motor integration is a good predictor of school achievement in terms of reading and mathematics (Hopkins *et al*., 2019). TVAS incorporates an aspect of spatial analysis due to the nature of the geometrical shapes that are required to be copied. The development of spatial skills occurs in early childhood and reduced spatial skills have been shown to be related to mathematical achievement (Carr *et al*., 2018).

The TVAS test is a paper-based task and requires the participant to copy patterns to an adjacent box. The task is shown in **Figures 3.9** and was not timed, with the participant permitted to correct mistakes. The task consisted of eighteen patterns presented in a booklet with a dot matrix adjacent for the geometrical shape to be copied to. The first two patterns are simple geometrical shapes using horizonal and vertical lines, with a 5-dot matrix adjacent. Patterns 3, 4 and 5 are more complex with a 9-dot matrix and contain oblique lines within the geometrical shapes. The next more difficult sets use a 25-dot matrix with increasingly complex geometrical shapes containing overlapping lines.

Figure 3.9: The Test of Visual Analysis grid patterns

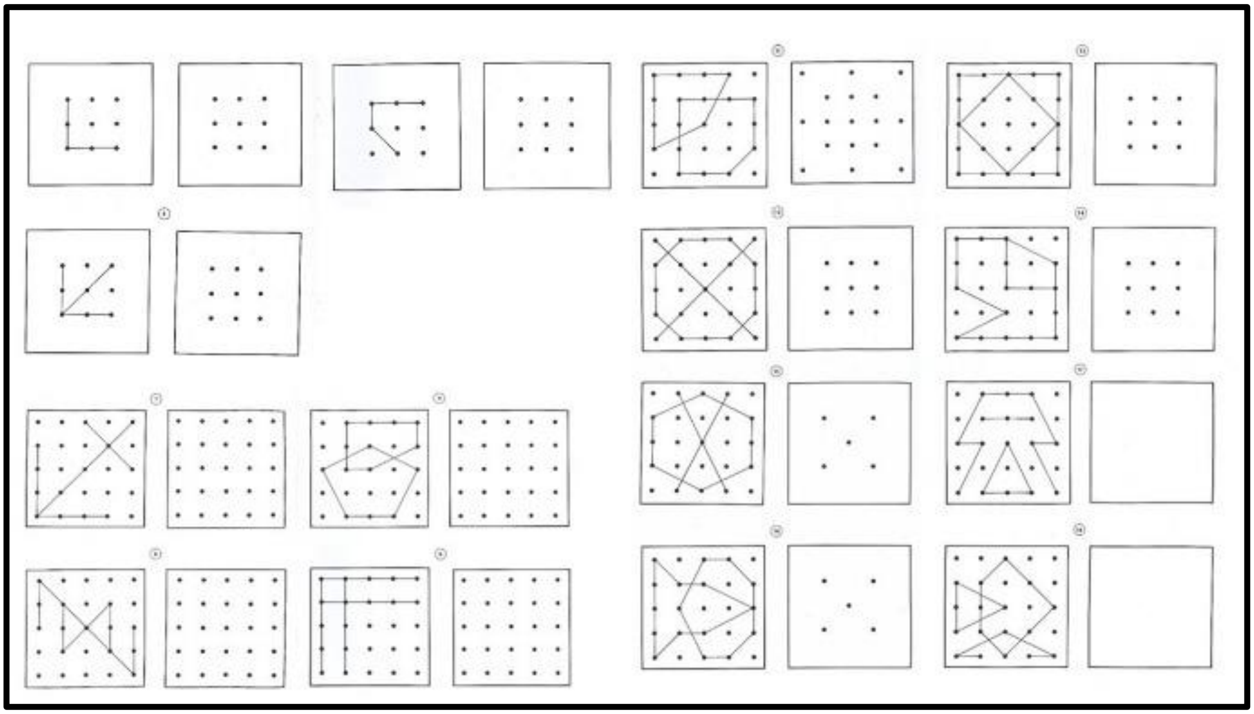


Figure 3.9. The Test of Visual Analysis (TVAS) grid matrix patterns showing the first simple grid matrix with horizontal lines and increasing in complexity to include oblique and overlapping lines. In the final matrices dots are progressively removed and require the participant to visualise where the dots should be, so they are able to copy the grid pattern. The final two patterns contain no dot matrix for support and require the participant to demonstrate advanced spatial recognition in addition to complex visual motor skills to copy the pattern.

Developmental Eye Movement Test:

The Developmental Eye Movement (DEM) test was originally developed to investigate saccadic eye movements (Richman and Garzia, 1990), but also correlates with reading ability and visual processing speed (Facchin, 2021). By giving an indication of reading ability and visual processing, the DEM test is helpful clinically in differentiating individuals at risk of reading ability delay (Ayton *et al.*, 2009). In Australia, the DEM test measures have been associated with academic performance in grade 3 students, based on national testing scores (Australian National Assessment Program for Literacy and Numeracy: NAPLAN) (Wood *et al.*, 2018).

The DEM test is composed of two subtests. The first subtest involves reading numbers vertically on two cards. There are 20 numbers on each side of the page arranged randomly using the numerals from 1 to 9, which are read vertically from top left to bottom, then top right to bottom as shown in **Figure 3.10**. The second subtest assessment card contains 80 random numbers (1 to 9) that are randomly spaced on horizontal lines that form a grid of 16 lines with 1.5 letter spacing between lines and with 5 numbers per line as shown in **Figure 3.11**.

Figure 3.10: Developmental Eye Movement test subset 1

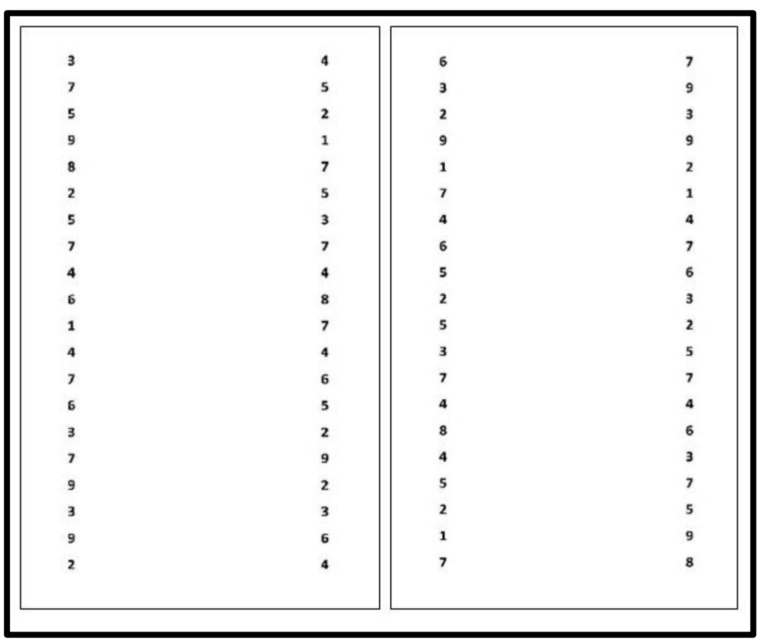


Figure 3.10. The Developmental Eye Movement (DEM) subset 1 consists of two test cards containing two rows of vertical numbers that are read horizontally starting from the top left to bottom left, then top right to bottom right as quickly and as accurately as possible.

Figure 3.11: Developmental Eye Movement test subset 2

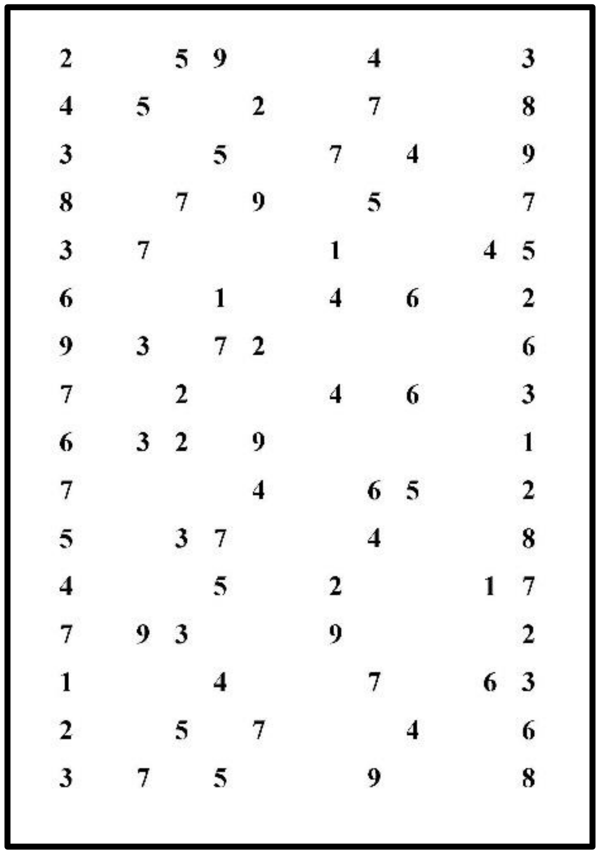


Figure 3.11. The Developmental Eye Movement (DEM) subset 2 test consists of horizontal numerals that are read aloud across the page from left to right as quickly and as accurately as possible. There are five numerals per line that are randomly spaced between 16 rows.

Time to complete the horizontal DEM subtest has the strongest correlation with reading skills (word recognition) (Ayrton *et al*., 2009) and academic performance based on reading and mathematics scores (Hopkins *et al*., 2019), which supports the use of the horizontal subtest as a measure for overall reading performance with printed material. Consequently, the vertical subtest was used as a practice test to familiarise the participants with the assessment process and to determine their ability to read numbers accurately, and the horizontal subtest completion time was used as a measure of functional vision.

The horizontal subtest was a timed test and was conducted NP and RP paper and text as shown in **Figure 3.12**. The time taken to read the numbers was recorded with an electronic stopwatch. Errors (missed or incorrect) in number reading resulted in one second being added to the total time for each incorrect response. The total (corrected) time to read the horizontal card was then recorded for both normal and RP reading tasks.

Figure 3.12: Horizontal Developmental Eye Movement test with different text polarity

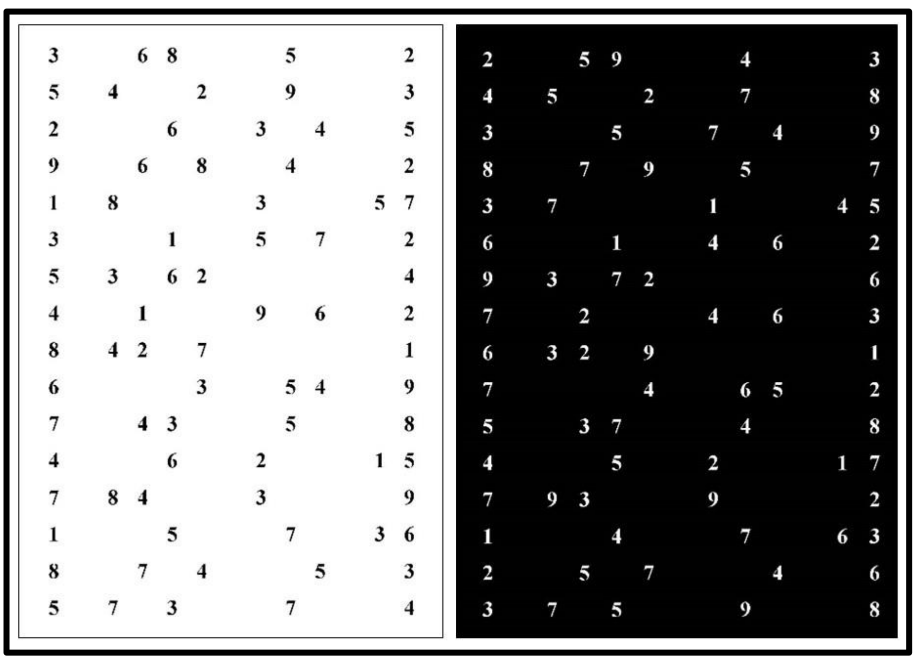


Figure 3.12. The normal and reverse polarity printed numerical text was used to assess reading performance based on the Developmental Eye Movement (DEM) subset 2. The numbers were read aloud from right to left and the time to complete reading the numbers on each card with different polarity was timed using an electronic stopwatch.

3.3.3 Feature Visual Search

A visual search task involves locating a specified target within a group of distractors. Previous findings have shown that search times are longer, and accuracy is reduced, in those with a VI compared to those with normal vision (Huurneman *et al*., 2014). In the study by Huurneman *et al.*, (2014) the search tasks were simple and complex and involved a comparison of reaction times (RTs) and eye movements in 37 VI and 11 comparison individuals aged between 6 to 8 years. The authors reported a main finding of slower and less accurate search performance in the VI group with nystagmus.

Visual search is an important aspect of visual functioning in a learning environment that places visual demands on the individual to develop an effective scanning, search, and location strategy to navigate learning material successfully. This may involve, identifying specific salient information in large amounts of text, analysing graphs to find key details, or synthesising data from tables. In addition, these tasks become more demanding throughout education and are essential for independent accessibility and learning (Seassau and Bucci, 2013).

Search Task

Participants performed this assessment sitting 40cm from a MacBook Air Laptop with an 11.6-inch display. Appropriate refractive correction was worn if required. The visual search task was run using MATLAB (The Mathworks Inc, Natick, MA, USA), which controlled the task and recorded the responses. The task involved determining whether a target (ellipse) was present in a screen of distractors (circles) shown in **Figure 3.13**. Matlab code was provided courtesy of Prof

Joshua Solomon, the City University London as previously described in detail (Constable *et al*., 2010).

Figure 3.13: Screen presentations for the visual search task

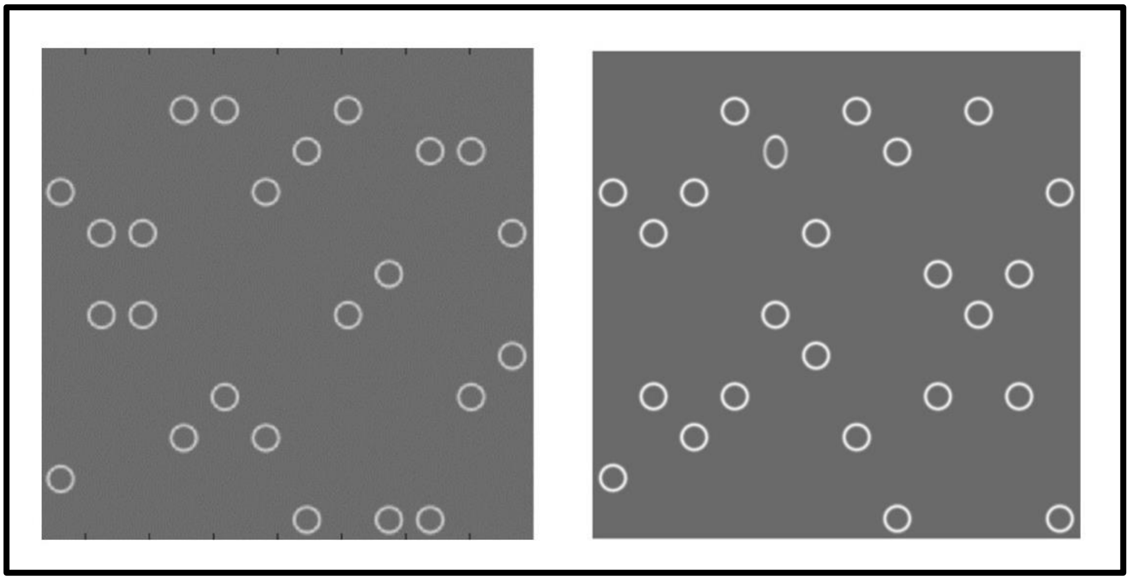


Figure 3.13. Display presentations for the feature search task with set size 24. Right figure shows the absent condition, and the left figure shows the target present condition in which the target ellipse present within the circular distractors. Presentations were random with the target (ellipse) either present or absent amongst set sizes of 4, 16 or 24 circular distractors.

Participants were required to respond to the presentation by pressing either “p” on the keyboard for target present, or “a” for target absent, and the time from presentation to response was recorded for each screen presentation. There were three different set sizes for the distractors of 4, 16 and 24 and there was a total of 80 randomised presentations.

Data from each presentation was removed if the search response time exceeded 10 seconds. The mean RT (in milliseconds) was calculated using the first eight correct responses. The initial eight presentations served as a practice trial and were not included in the mean RT analysis. The remaining seventy-two responses were organised based on set-size and the presence or absence of the target. The percentage of correct responses was determined by dividing the number of the first eight correct responses by the total number of presentations required to achieve eight correct responses. Any observation with an accuracy equal to or below 50% (i.e., chance level) was excluded.

3.3.4 Colour Vision

Within an education environment, colour can be used in varying ways to teach children. In early childhood, this may be activities involving coloured objects and drawings. In later years colours may be used in educational material to differentiate information, such as details on graphs or in tables.

The Ishihara colour vision test (Clark, 1924) is a widely used test in clinical practice used to screen for red-green colour deficiencies. However, failure on this test may not fully represent the individual’s functional difficulty differentiating colours in the classroom. In view of this, the standard clinical Ishihara consisting of 24 pseudoisochromatic plates with 13 of these plates containing numbers which required naming was used, and an additional functional colour assessment was also performed. This involved asking the individual to correctly match coloured pens with the correct coloured lids. This practical functional assessment of colour matching was devised specifically for this study and gave a visual representation of which colours might be confused by the participants with a VI and is shown in **Figure 3.14**.

Figure 3.14. Functional colour vision test

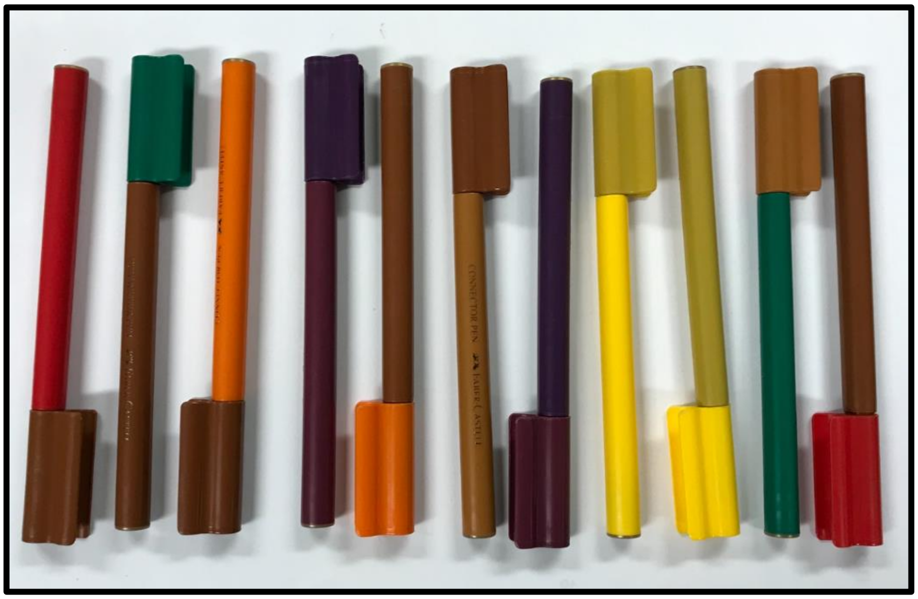


Figure 3.14. Example of a functional colour vision test result on a student with a colour vision defect. Students were given coloured pens with mis-matched coloured lids and are asked to re-sort the pens and lids so that they were the same colours. This colour matching task was based on functional ability and created specifically for this study as a practical test of colour matching that may be encountered in the classroom.

3.3.5 Modified Cone Adaptation Test

The Modified Cone Adaptation Test (MCAT) is a more formal functional demonstration of how well an individuals' vision adapts to changes in illumination. In the classroom, there are often changes in room lighting when lights are switched on and off for videos, or when the individual enters the classroom from a bright outdoor play area into the lower illuminated indoor area. The MCAT provides information on visual adaption to lighting changes or the time that may be needed to transition from different illumination levels for an individual.

The MCAT consists of thirty-six coloured blocks, twelve each of white, red, and blue (Deshpande *et al*., 2016). The participant was asked to sort the blocks into the 3 different colours under classroom illumination levels (ranging from 300-400 lux). The room was then darkened, including closing all shades and blinds so that the room was as dark as possible with room illumination <1 lux. The participant was then asked to re-sort the mixed pile of blocks as they dark adapted. During dark adaptation, with normal cone function the typical observer would sort the blocks in order from white to blue to red as the cones adapted. An inability to sort the blocks correctly in 10 seconds indicates defective cone adaptation (Deshpande *et al*., 2016). A reduced time (<10 seconds), but correct sorting was considered as a slow result, whereas miss-sorting the blue and red blocks was considered as a failure as shown in **Figure 3.15**.

Figure 3.15: Example of a failed modified cone adaptation test

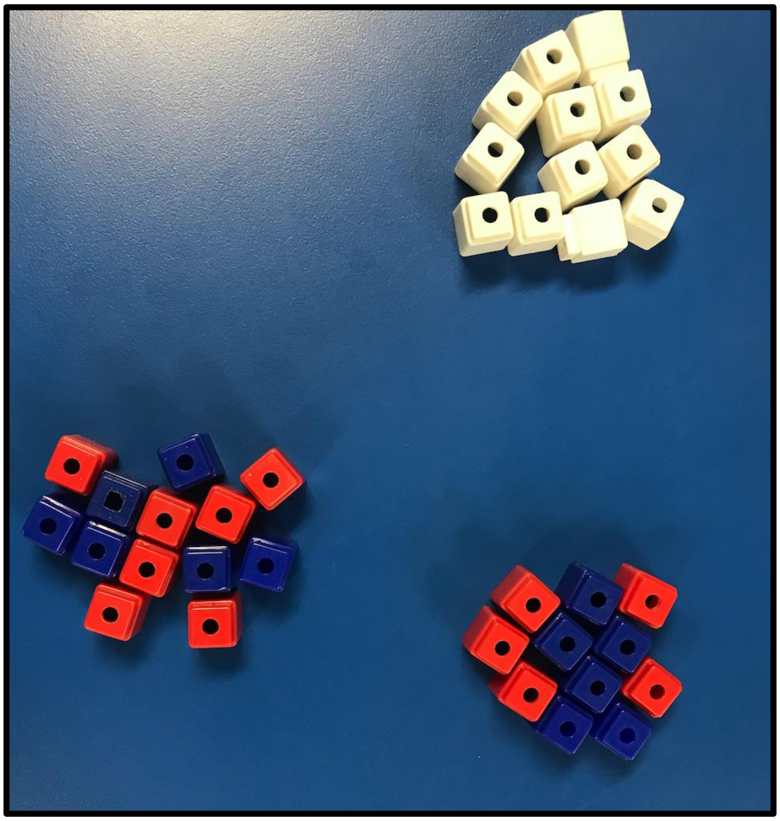


Figure 3.15. An example of a failed test result in the modified cone adaptation test where during dark adaptation the individual was unable to correctly discriminate between the red and blue coloured blocks due to reduced cone function.

3.4 Ethics

Ethical approval was granted by the The Women's and Children's Hospital, Human Research Ethics Committee, Adelaide, South Australia (HREC/19/WCHN/177) on the 17th of March 2020 and provided in **Appendix 7**.

An application for data access, site access and to undertake research was submitted to the South Australian Department of Education and was approved in February 2020. Site access was granted to all Department of Education Schools within South Australia. See **Appendix 7.** The project was in collaboration with and had the support of The South Australian School and Services for Vision Impaired and The Statewide Support Service for Children with a Vision Impairment.

Parental informed consent was obtained prior to participation and a copy of the information leaflets and consent forms are provided in the **Appendix 8.**

3.5 Data Storage

All data collected from the participants was de-identified (coded) and electronically stored on secure servers at Flinders University. Codes for re-identification were stored separately in a secure file on Flinders University Servers and were password protected.

Deidentified data included, subject id, age, gender, year level, diagnosis of VI and measures of visual function and functional vision assessments.

3.6 Statistical Analysis

Participants were classified into three groups for analysis based on the WHO classification of mild, moderate, and severe VI independent variables.

Group Severe: Severe Vision Impairment*:* 1.00-1.52 logMAR (6/60-6/190).

Group Moderate: Moderate Vision Impairment 0.50-0.99 logMAR (6/19-6/60).

Group Mild: Mild Vision Impairment 0.20-0.49 logMAR (6/9-6/18).

VI groups (mild, moderate and severe) were then correlated with tests of vision as the dependent variables which included:

1. VA (logMAR): Threshold High Contrast Binocular Acuity: logMAR VA measured with four alternative forced choice random Landolt C (Freiburg Acuity Chart - FrACT) (Bach, 1996; 2007).
2. LogCS (logMAR): Log Contrast Sensitivity threshold: logCS measured using FAFC random Landolt C at 3 times Threshold High Contrast VA (Bach, 1996; 2007; Brussee *et al*., 2017; Giacomelli *et al*., 2010; Pelli and Bex, 2013).
3. Reaction Time (RT) (msec): Visual Search: Average reaction time for 4, 16 and 24 distractors with target present or absent (Huurneman *et al*., 2014; Seassau and Bucci, 2013).
4. CPS (unit): Critical Print Size - the critical font size required to maximise reading speed using the MNREAD program (Legge *et al*., 1989).
5. MRS (words per minute) Maximum Reading Speed (MRS): maximum reading speed using the MNREAD program (Legge *et al*., 1989).

6. NRM (seconds): Development Eye Movement (DEM) reading time: Number reading speed (NRS) on printed material (Ayton *et al*., 2009; Facchin, 2021; Richman and Garzia, 1990; Wood *et al*., 2018).
7. Crowding Intensity (logMAR): the difference in high contrast logMAR distance VA measures between an uncrowded and crowded Landolt C (Huurneman *et al*., 2012; 2016a; Pelli, 2008; Pelli and Tillman, 2008; van Genderen *et al*., 2012).
8. RR (no units): Reading Reserve: Ratio of the smallest print the participant can read (reading acuity) to the optimum print size for reading (CPS) (Lueck *et al*., 2003).
9. 30Hz (μV): Amplitude of the 30Hz full field flicker ERG (Maa *et al*., 2016; Robson *et al*., 2022).

Categorical variables:

1. Gender: 2 levels, Male or Female.
2. Polarity: Normal or Reverse.
3. Diagnosis: 4 levels: Retinal dystrophies, Albinism, Optic Nerve Disorders, Others.
4. Educational level (grade/year level).
5. Age (Years).

All data was analysed for normality using the Kolmogorov-Smirnov test, with a non-significant result (Sig value more than .05) indicating normality, then appropriate parametric or non-parametric tests were employed to evaluate the interactions between the VI group and their dependent and independent variables and are described in the chapters containing the results. A *p*-value of <.05 was considered significant in all cases.

To determine tests of functional vision that represented functional deficits in the classroom and to construct a representative framework for assessment and support. Several aspects of functional vision tests were explored, and results compared with published reference measures, where available, to investigate the impact that childhood VI had on these functional tests. Certain aspects of functional tests were investigated to analyse what conditions improved a student's performance, for example the comparison of reading performance with normal or reverse polarity. Pathology groups were also considered to explore possible associations with disease characteristics and visual function.

Examples of investigations that guided the development of a clinical framework were:

- The CPS that allowed MRS so that this optimal font size could be used in text material.
- High contrast VA and the impact of crowding to accommodate letter spacing.
- MRS compared with age matched controls to estimate the additional time required to complete a reading task.
- The impact of NP and RP print on reading performance.
- Visual Search performance as measured by RT and accuracy to determine time adjustments when searching for material.
- Visual processing speed and accuracy to support visual motor integration.

- Reading reserve to reduce visual fatigue by providing additional breaks or adjustment of learning media.
- Impact of pathology, including nystagmus as a possible clinical feature with which to plan the most appropriate support.

CHAPTER 4 : VISUAL ACUITY AND FUNCTIONAL VISION

This chapter outlines the main group characteristics and findings between measures of VA and visual function in the study population. Given that VA is the main measure of visual function that determines the level of support of an individual with a VI receives, this part of the thesis compared distance VA with functional vision metrics to evaluate the null hypothesis that:

- Distance VA is a suitable measure of visual function.

4.1 Participants

Eighty students were initially recruited to evaluate functional vison and VA, of these fifty-four met inclusion criteria with reasons for exclusion including: co-disabilities (autism spectrum disorder, dyslexia), VI too severe (Braille users) or the individual was not able to read the largest font size (1.2 logMAR) on the MNREAD at 10cm. Not all participants were able to complete all assessments with the included participant numbers (*n*) for each test indicated with the outcome measures. All assessments were either conducted at SASSVI unless the child (parents) were unable to travel to SASSVI, then the assessment was performed at the student's mainstream school in an appropriate room.

Of the fifty-four included participants, (male (*n*=31); female (*n*=23)) the mean age was 12.2 ± 3.0 years, with the male mean age of 12.0 ± 3.0 years, and female 12.4 ± 3.1 years. School grade ranged from reception to year 12, mean 6.3 ± 3.0. In males, the mean school grade was 6.0 ± 3.0, and for females the school grade was 6.6 ± 3.2. VAs ranged from 0.18 (6/9) to 1.52 (6/200) logMAR. Overall, mean VA was 0.73 logMAR (6/32) ± 0.35, with males 0.79 logMAR (6/37) ±

0.38, and females 0.66 logMAR (6/27) ± 0.30. Nystagmus was a common feature in the participants with 80% having nystagmus in primary gaze. See **Table 4.1** for summary.

Table 4.1: Participant characteristics of the vision impairment group

	Total *n*=54	**Male *n*=31**	**Female *n*=23**
Age (years)	12.2 ± 3.0	12.0 ± 3.0	12.4 ± 3.1
School Grade	6.3 ± 3.0	6.0 ± 3.0	6.6 ± 3.2
Visual Acuity (logMAR)	0.73 ± 0.35	0.79 ± 0.38	0.66 ± 0.30
Nystagmus Present	80%	71%	91%

Table 4.1. Participant characteristics of the vision impairment study population. Values are mean ± standard deviation (SD).

4.1.1 Causes of Vision Impairment

Causes of VI included both developmental and acquired ocular conditions. Congenital disorders were ocular albinism, retinal dystrophies, optic nerve disorders, infantile nystagmus, congenital glaucoma, congenital cataract, aniridia and iris/lens coloboma. Acquired ocular conditions included retinal detachment, uveitis, and ROP. In the VI group, the majority had albinism (*n*=15, 27.8%) or a retinal dystrophy (*n*=15, 27.8%). Retinal dystrophies covered a wide range of diagnoses including cone-rod dystrophies, rod-cone-dystrophy, and macular (Stargardt's) as depicted in **Figure 4.1,** with some participants classified as having a 'general retinal dystrophy' of unspecified origin. One limitation in such cases was that access to the individual's medical records was not possible, making it difficult to fully characterise these cases without a complete medical history. Different retinal dystrophies will have different visual behaviour characteristics based on the age of onset, whether they are predominantly macular or retinal and if they affect primarily the rod or cone pathways which will influence the overall visual function of the affected individual (Homan, 2017). Optic nerve disorders included ONG, ONH and Optic Neuropathy were also amongst the pathological causes of VI in the included participants with the distribution of pathologies shown in **Figure 4.1** of which there were four main pathological groupings including: retinal dystrophies, albinism, optic nerve disorders, and an others group which encompassed the remaining pathologies.

Figure 4.1: Distribution of pathologies

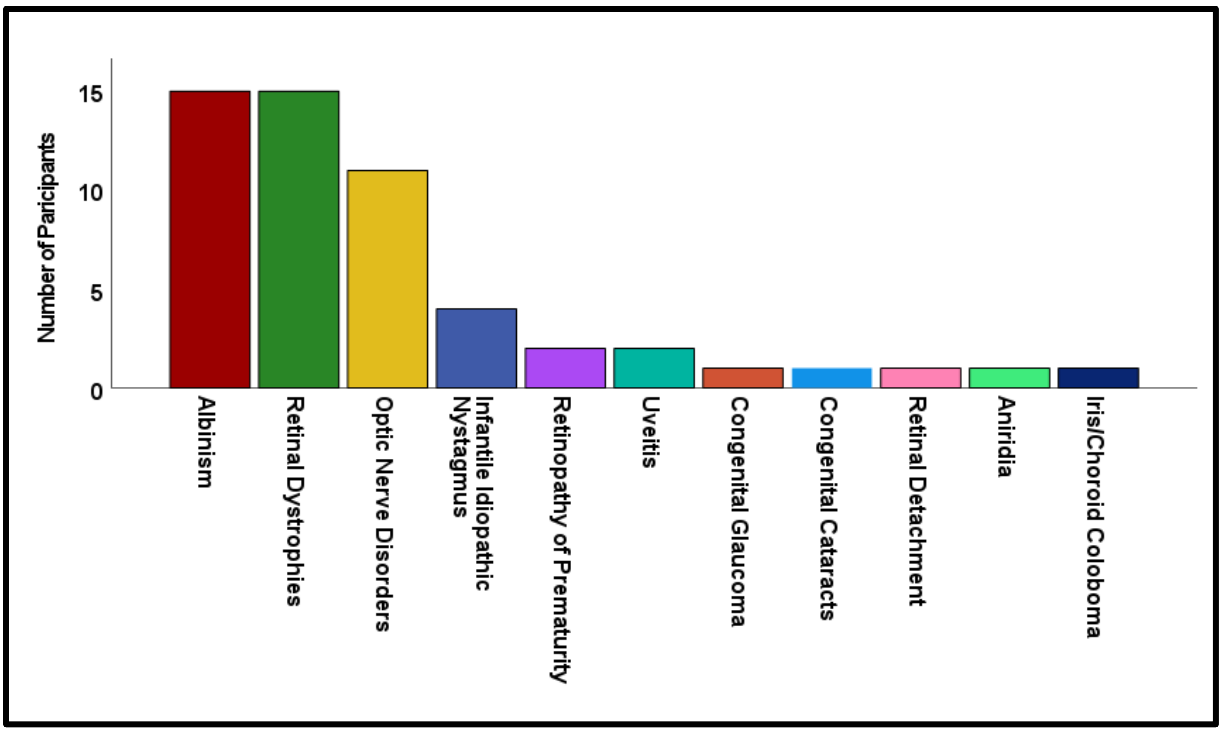


Figure 4.1. Distribution of primary pathology in the vision impairment group. The most common pathologies were albinism and retinal dystrophy.

4.2. Correlations of Visual Acuity and Visual Function

4.2.1 Contrast Sensitivity

From the included participants (*n*=47), the mean value for contrast sensitivity (logCS) using FrACT was 1.27 ± 0.44 (range 0.37 to 2.02).

Contrast Sensitivity was correlated with high contrast VA, 30Hz flicker amplitude and crowded VA. There was a significant negative correlation between contrast sensitivity (logCS) and crowded distance VA (p=.004, r^2=0.1), with contrast sensitivity reducing with decreasing VA. There was also a significant positive correlation between contrast sensitivity and the 30Hz flicker amplitude (p=.04, r^2=0.002), with students having a higher ERG amplitude demonstrating higher contrast sensitivity measures.

4.2.2 Reading Ability and Contrast Sensitivity Thresholds

Contrast sensitivity was correlated with functional reading metrics, including reading acuity, CPS and MRS. There was a significant negative correlation between contrast sensitivity and reading acuity both in NP (p=.002) and RP (p=.02), with reading acuity decreasing with reduced contrast sensitivity. Contrast sensitivity and critical print size also demonstrated a significant negative correlation in both NP (p=.001) and RP (p=.007), with students requiring a larger optimum font size with lower contrast sensitivity measures. There were no correlations between contrast sensitivity measures and the MRS under RP or NP conditions as shown in **Table 4.2**.

Table 4.2: Correlations between contrast sensitivity and reading metrics

logCS vs Reading Metrics	**Normal Polarity**	**Reverse polarity**
Reading Acuity (logMAR)	***p* =.002** $r^2 = 0.20$	***p* =.02** $r^2 = 0.11$
Critical Print Size (logMAR)	***p* =.001** $r^2 = 0.21$	***p* =.007** $r^2 = 0.15$
Maximum Reading Speed (WPM)	*p* =.0.91 $r^2 = 0.03$	*p* = 0.96 $r^2 < 0.001$

Table 4.2. Correlation of contrast sensitivity (logCS) with each of the three main functional reading measures under normal and reversed polarity conditions. High contrast Reading acuity, Critical Print Size and Maximum Reading Speed.

As expected, there was a significant negative correlation between contrast sensitivity and reading acuity in NP (p=.002) and RP (p=.02) conditions, with a lower contrast sensitivity measure requiring a larger font size. Similarly, there was a significant negative correlation between low contrast sensitivity and CPS in NP (p=.001) and RP (p=.007) conditions. There were no significant relationships between contrast sensitivity and MRS under NP or RP conditions (p>.91).

4.2.3 Crowding, reading reserve and visual processing

Contrast sensitivity correlated positively with measures of crowding, reading reserve and visual processing measures of the DEM scores and negatively with TVAS. There was a significant positive correlation between contrast sensitivity and DEM with RP (p=.03) print only, with lower contrast sensitivity associated with a faster time to read the numbers in RP font, as summarised in **Table 4.3**.

Table 4.3: Contrast sensitivity, crowding, reading reserve and visual processing

Crowding Intensity (logMAR)	**TVAS (score)**	**DEM (NP)**	**DEM (RP)**	**Reading Reserve (NP)**	**Reading Reserve (RP)**
p = .20 $r^2 = 0.06$	p =.54 $r^2 = 0.92$	p =.33 $r^2 = 0.03$	***p* = .030** $r^2 = 0.16$	p =.76 $r^2 = 0.002$	p = .99 $r^2 < .001$

Table 4.3: Correlation co-efficient between contrast sensitivity and Crowding Intensity, Test of Visual Ability Score (TVAS), Developmental Eye Movement (DEM) reading time under normal polarity (NP) and reverse polarity (RP) conditions and the reading reserve under NP and RP conditions. The only significant correlation was found between contrast sensitivity and the DEM reading time in RP (p=.030). All other relationships were non-significant (p>.20).

4.3 Visual acuity and reading print size

This Section of the thesis contains material from published work

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Visual acuity and reading print size requirements in children with vision impairment

Lynne Loh, Mallika Prem-Senthil and Paul A Constable
College of Nursing and Health Sciences, Caring Futures Institute, Flinders University, Bedford Park, South Australia, Australia

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This part of the thesis was to evaluate the relationship between distance VA and print size reading ability in children with a VI. Secondary aims were to investigate the possible impact of underlying pathology on reading ability as a potential marker to guide interventions in the classroom. Background and rationale for this part of the study are provided in the Introduction chapter of this thesis to improve educational outcomes for children with a VI (**Chapter 1**).

4.3.1 Methods

Participants

Seventy children were recruited from South Australia's state-wide support service for children with a vision impairment. All children had previously been diagnosed, by an ophthalmologist, with a pathological vision impairment. Eligible children, in full time primary or secondary education, were identified by specialist low vision trained state-wide support teachers in South Australia. The MNREAD uses vocabulary from high frequency words used in reading material of 8-year-old children, and so students were only included if their teacher reported a reading level age of eight years and above.

Potential participants were excluded (*n*=23) if they had a diagnosis of dyslexia, language or communication disorder, intellectual disability (reported full scale intelligence quotient <75) or were unable to read the largest font sentences (1.2 logMAR) on the MNREAD chart at 10cm. Based on the level of binocular distance VA, participants were grouped into three levels for analysis. The VA groups were defined based on the definitions of mild, moderate, and severe vision impairment by the WHO. Group-severe: 1.00-1.52 logMAR (6/60-6/190), group-moderate: 0.50-0.99 logMAR (6/19-6/60), and group-mild:0.20-0.49 (6/9-6/18).

The forty-seven eligible participants (28 male and 19 female) with age (mean ± SD) 12.2 ± 3.0 (range 5.0-18.0) and school grade 6.3 ± 3.1 (Reception to grade 12) underwent clinical measures of distance VA and full reading analysis. Pathological causes of VI were predominantly inherited retinal dystrophies (34%) or albinism (28%). Optic nerve disorders, including ONH, ONG and optic neuropathy accounted for 15% of participants. There were two participants with ROP and one each of aniridia, iris/choroid coloboma, uveitis, retinal detachment, congenital glaucoma, and congenital cataracts. Idiopathic infantile nystagmus was present in three, with the overall presence of nystagmus secondary to a primary pathology in 83% of the participants. **Figure 4.2** shows the distribution of pathologies within the VI group. There were no-significant differences ($p > .08$) between VI groups for gender, age, academic year, or the presence of nystagmus as detailed in **Table 4.4**.

Figure 4.2: Distribution of primary pathological cause of vision impairment

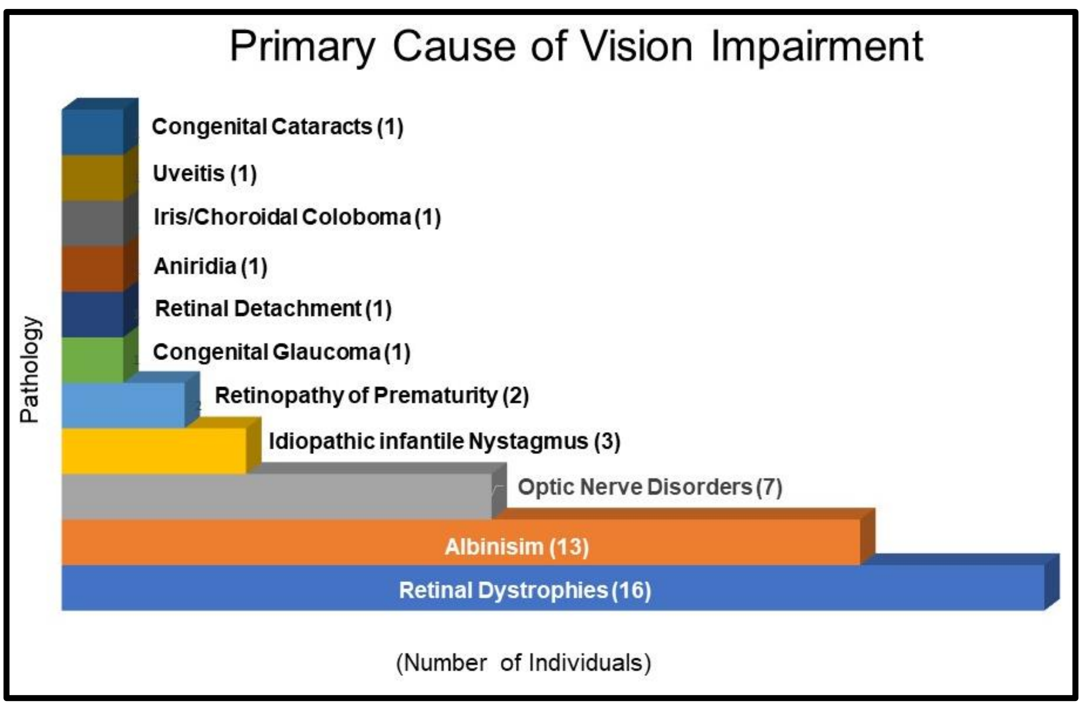

Figure 4.2. Distribution of the primary cause of vision impairment in the study population with the majority being due to either an inherited retinal dystrophy or albinism. Figure from Loh *et al.*, (2023).

Table 4.4: Characteristics of vision impairment groups

	All (*n*=47)	**Severe (*n*=16)**	**Moderate (*n*=17)**	**Mild (*n*=14)**	***p*-value**
Gender (M:F)	28:19	12:4	11:6	5:9	.08
Age (years)	12.2 ± 3.0	12.5 ± 2.9	11.9 ± 3.0	12.5 ± 3.2	.97
Academic Year	6.3 ± 3.1	6.7 ± 2.9	6.0 ± 3.3	6.4 ± 3.2	.42
Nystagmus Present %	83	70	94	86	.15
Log CS	1.25 ± 0.45	1.02 ± 0.36	1.21 ± 0.41	1.56 ± .43	.006

Table 4.6 Characteristics of the vision impairment study population by visual acuity group (mild, moderate, and severe). All values are mean ± SD. CS Contrast Sensitivity, M= male, F= female. Test of significance – Chi-squared for gender and nystagmus, and analysis of variance (Mann-Whitney U test for age, logCS and academic year.

Reading Performance

Reading analysis was performed using the MNREAD (Calabrèse *et al*., 2018) on an iPad7, running iOS version 14.4.1. MNREAD was used to assess reading acuity (the smallest print size that could be read without significant errors) and CPS (the smallest font size that could be read at the MRS) (Virgili *et al*., 2004). The iPad was mounted in landscape mode and the reading distance constantly monitored by a fixed metal ruler. Reading distance was fixed at 40cm unless the participant was unable to read the largest font at this distance, then the reading distance was set at 20cm. Each sentence presentation was initiated and stopped by the examiner when the participant began and finished reading each sentence during the trials. Reading tests were performed with random sentence sets to avoid memorisation and an average of results taken. Room illumination was typically between 450-500 lux.

For comfortable, sustained reading performance, the measurement of the absolute minimal reading acuity achieved is not as important as the functional measure of CPS, which is the smallest font size before reading speed begins to decrease (Bailey *et al*, 2003; Legge *et al*., 1992; Lueck *et al.*, 2003). The CPS is defined as the print size at which subsequent smaller print sizes were read at 1.96 standard deviations slower than the mean of the preceding print sizes (Calabrèse *et al*., 2018).

Statistics

Relationships between distance VA and reading performance (reading acuity and CPS) were evaluated using Pearson's correlation coefficient. All analyses were performed using IBM SPSS version 28. Non-parametric tests (Chi-Squared Test of Independence, Kruskal-Wallis Test) were used as appropriate to compare parameters between the three acuity groups. All values are reported as mean ± standard deviation (SD) unless otherwise specified.

4.3.2 Results

Distance visual acuity and reading performance

The group-severe participants demonstrated no significant correlation between binocular distance VA and reading acuity (p=.64, r^2=02) or CPS (p=.78, r^2=.006) (**Figure 4.3**). The participants within the group-mild, with the highest level of VA, also demonstrated no significant correlation between distance VA and reading acuity (p=.82, r^2=.005) or CPS (p=.43, r^2=.05). The regression plots are shown in **Figure 4.5**.

In contrast the participants in the group-moderate demonstrated a significant correlation of distance VA to reading acuity (*p*<.001, r^2=.58) and CPS (*p*=.03, r^2=.27). See regression plot in **Figure 4.4**.

Significant correlations were demonstrated between reading acuity and CPS in group-severe (*p*<.001) and group-moderate (*p*=.04). There was no correlation between reading acuity and CPS in the group-mild (*p*=.06). See **Table 4.5** for summary of correlations.

Figure 4.3: Visual Acuity and Reading: Group-Severe

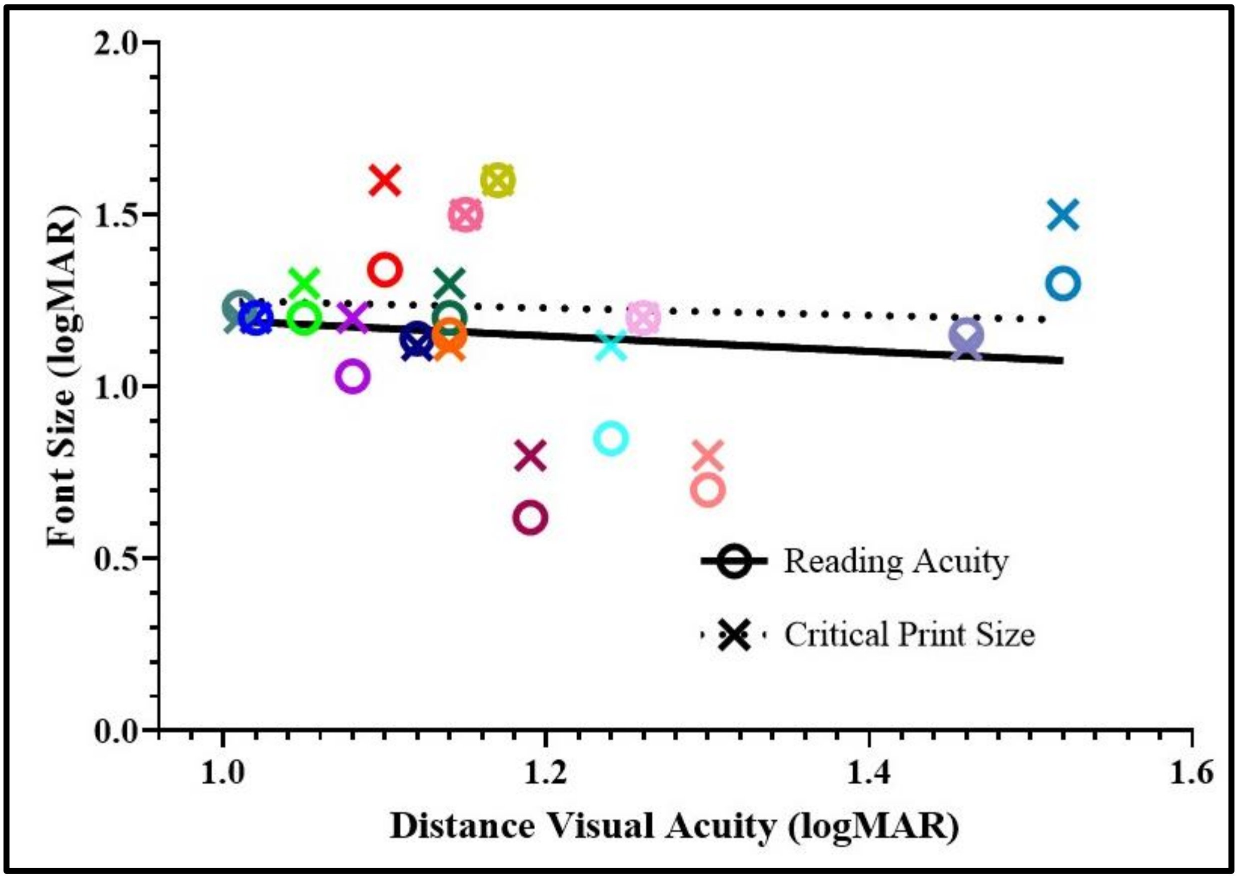

Figure 4.3. Relationship between reading acuity (circles), critical print size (crosses) and distance visual acuity for *n*=16 subjects in the group-severe. Each colour represents an individual subject. No significant correlations were found in the acuity range 0.20-0.49 LogMAR for minimum reading acuity (*p*<.82) or critical print size (*p*<.43). With regression lines for reading acuity (solid line) and critical print size (dotted line). Figure from Loh *et al*., (2023).

Figure 4.4: Visual Acuity and Reading: Group Moderate

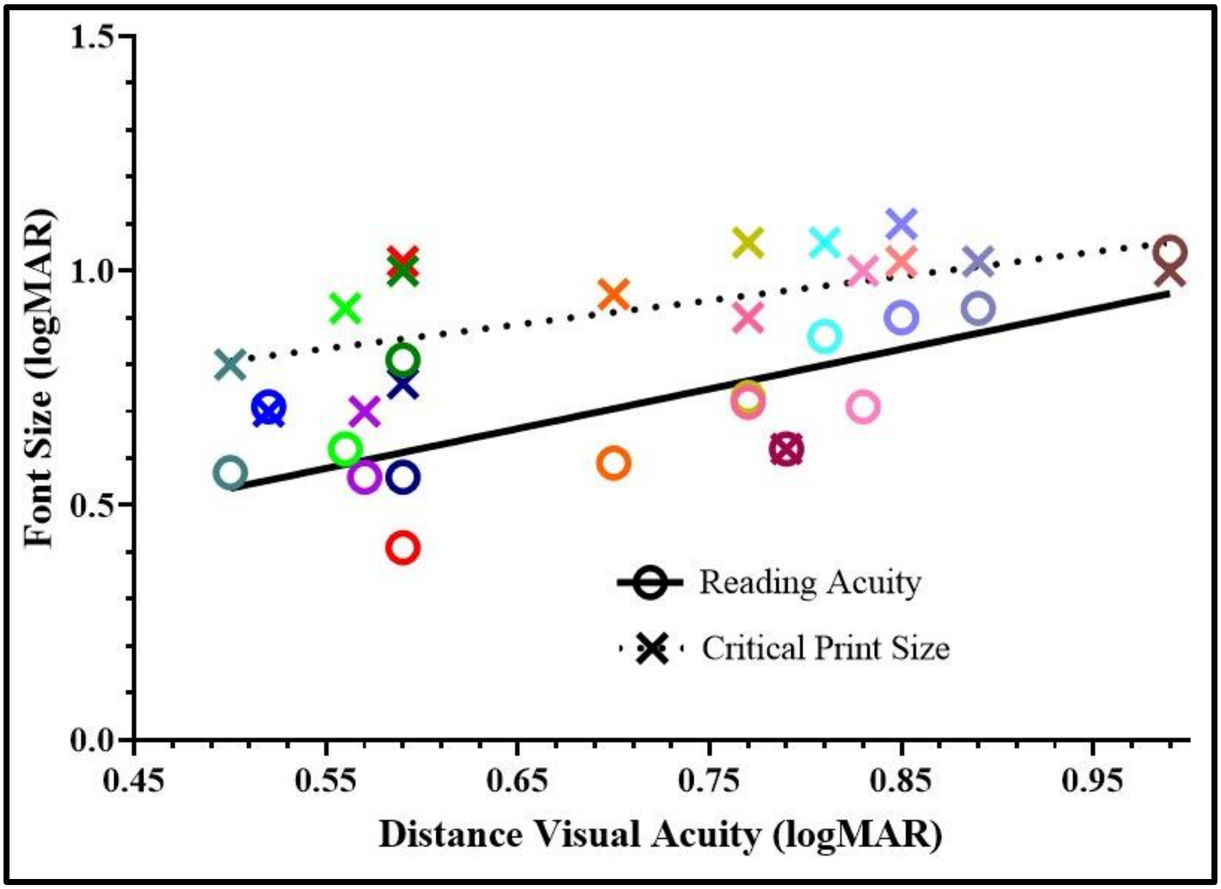

Figure 4.4. Relationship between reading acuity (circles), critical print size (crosses) and distance visual acuity for *n*=17 subjects in the group-moderate. Each colour represents an individual subject. Significant correlations were found in the acuity range 0.50-0.99 logMAR for minimum reading acuity (*p*<.001) or critical print size (*p*<.03). With regression lines for reading acuity (solid line) and critical print size (dotted line). Figure from Loh *et al*., (2023).

Figure 4.5: Visual Acuity and Reading: Group-Mild

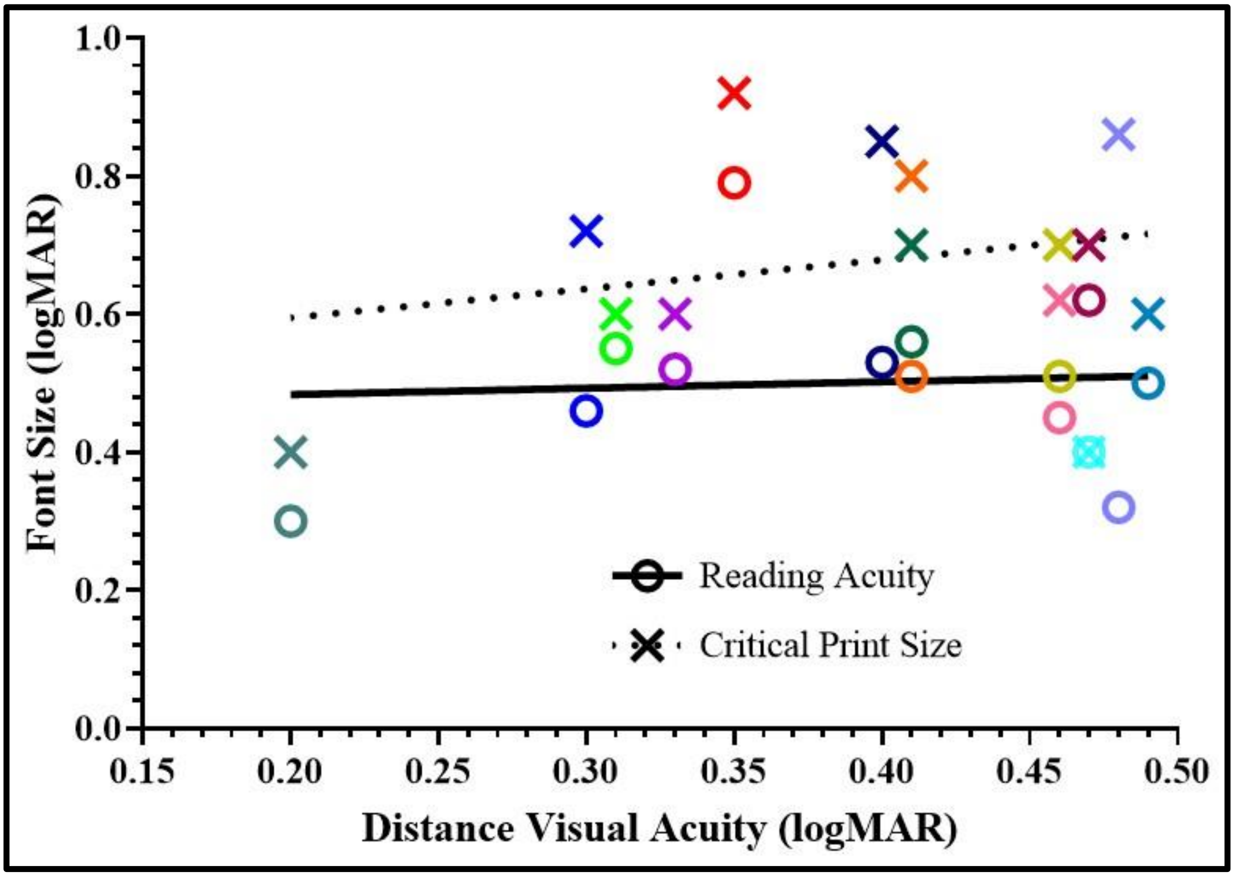

Figure 4.5. Relationship between reading acuity (circles), critical print size (crosses) and distance visual acuity for *n*=14 subjects in Group-mild. Each colour represents an individual subject. No significant correlations were found in the acuity range 0.20-0.49 LogMAR for minimum reading acuity (p=.82) or critical print size (p=.43). With regression lines for reading acuity (solid line) and critical print size (dotted line). Figure from Loh *et al*., (2023).

Table 4.5: Correlation of Visual Acuity and Reading

	Severe	**Moderate**	**Mild**
Distance Visual Acuity and Reading Acuity	r^2=.02 *p*=.64	r^2=58 *p*<001	r^2=006 *p*=.82
Distance Visual Acuity and Critical Print Size	r^2=.006 *p*=.78	r^2=.27 *p*=.03	r^2=05 *p*=.43

Table 4.5: Correlation coefficients and significance levels for distance and near measures of acuity and reading in the three vision impaired groups (mild, moderate, and severe). There was a significant correlation between distance visual acuity and reading performance for the group-moderate only.

Pathology and reading performance

Within the group-moderate (*n*=17), that was comprised predominantly of individuals with an inherited retinal dystrophy (*n*=10), there was a significant correlation between distance VA and reading acuity (*p*=.008, r^2=.61) but not CPS (*p*=.07, r^2=.35) of the individuals specifically with an inherited retinal dystrophy as shown in **Figure 4.7**. In contrast, for the group-mild (*n*=14), which was comprised predominantly of individuals with albinism (*n*=9) as shown in **Figure 4.6** there were no significant correlations between distance VA and reading acuity (*p*=.84, r^2=.006) or CPS (*p*=.99, r^2<.001). The group-severe contained a large variation of pathologies and so no direct comparisons could be made between acuity measures and a specific pathology sub-group as depicted in **Figure 4.8**.

Figure 4.6: Distribution of cause of vision impairment: group-mild

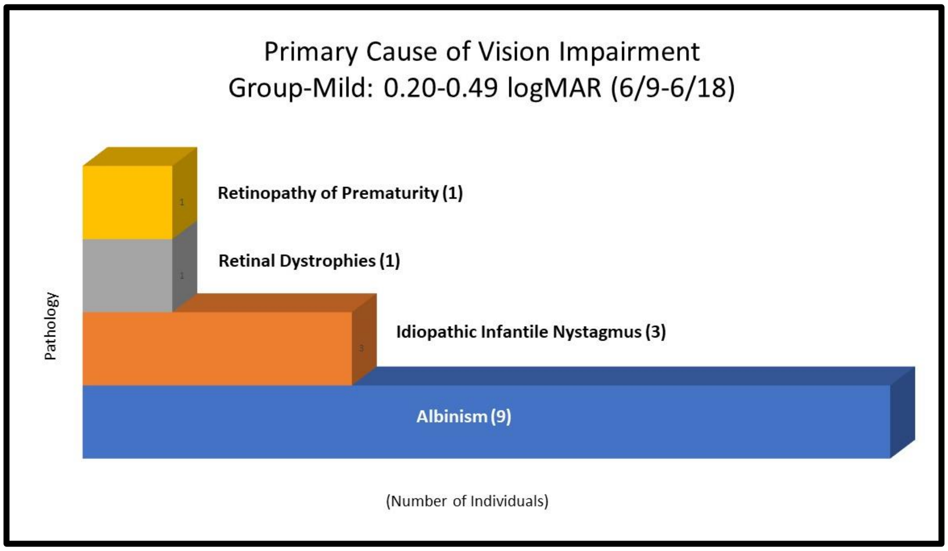

Figure 4.6. Distribution of causes of vision impairment in the group-mild, with a large proportion of students with albinism (*n*=9).

Figure 4.7: Distribution of pathology in group-moderate

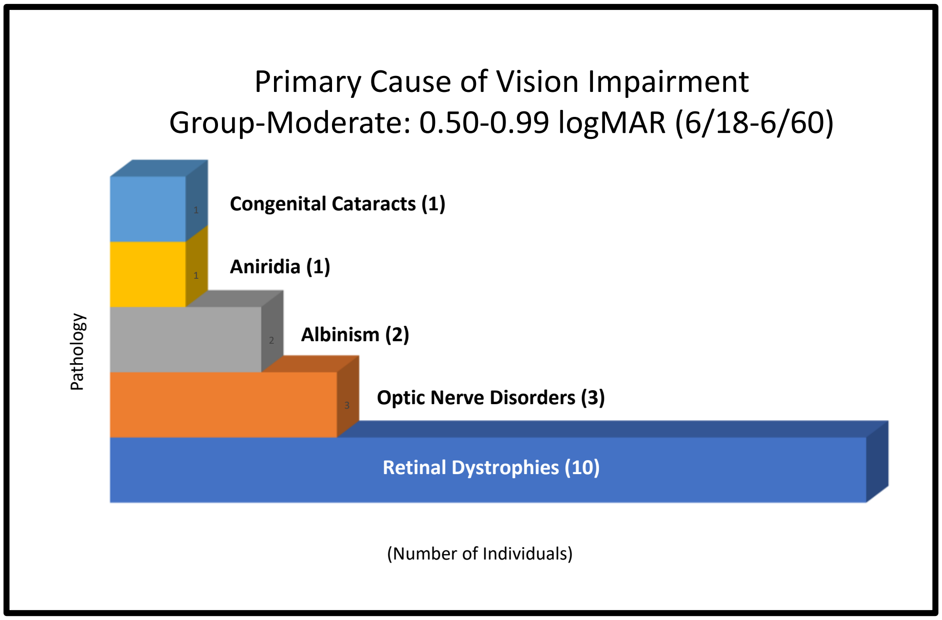

Figure 4.7. Distribution of the causes of vision impairment in the group-moderate, with a large proportion of students with retinal dystrophies (*n*=10).

Figure 4.8: Distribution of pathology in group-severe

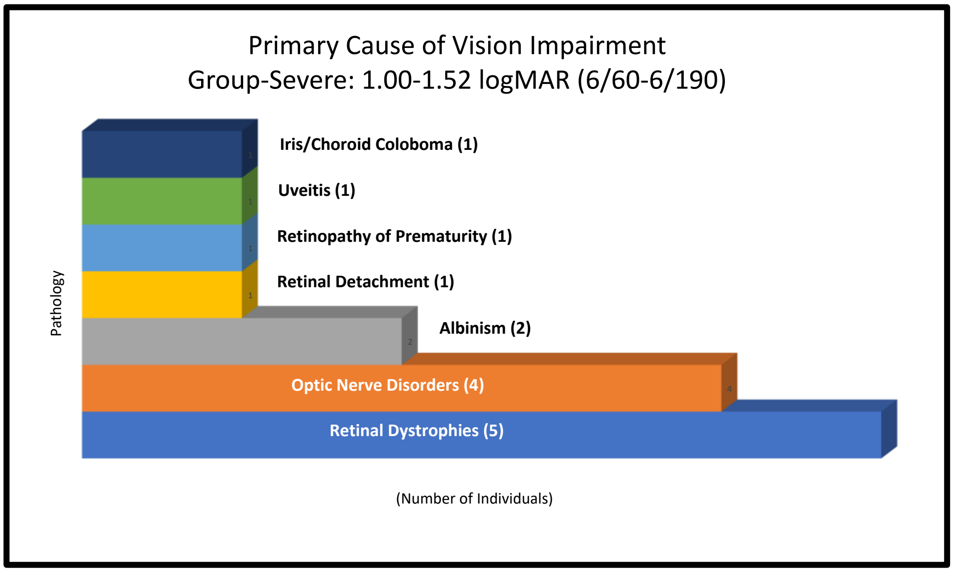

Figure 4.8. Distribution of the causes of vision impairment in the group-severe, with no dominant cause in this group.

4.3.3 Discussion

The main findings reported here that contribute to the framework for VI assessment was that there were no significant correlations between binocular distance VA with reading acuity or CPS (p>.47) for children whose VI is classified as being mild or severe. Therefore, distance VA is not a good predictor of reading ability for children whose distance acuity lies between the ranges of 1.00-1.52 logMAR (group-severe) and 0.20-0.49 logMAR (group-mild). Within the group-severe, a non-significant relationship was not unexpected given the lower levels of distance VA for this group. For these individuals, it is therefore important to evaluate their reading font size to determine the optimum size to ensure accessibility to their learning materials. While some of these participants could adequately access print materials in enlarged format, this study indicated that due to the variation in print sizes that were read, some students with similar VAs may require a larger font size and therefore a more efficient way to access learning materials in the classroom. For the group-mild individuals, the findings also supported a lack of correlation between distance VA and reading performance and therefore in this group, reading performance measures are more likely to be a more reliable indicator of reading ability rather than VA.

In contrast, the group-moderate participants, did show a significant correlation between binocular distance VA measures and font size requirements for reading based on CPS p=.03 and reading acuity (p<.001). The reasons for this are uncertain given that between the groups there was no significant differences in nystagmus, age, sex, or academic year levels. One explanation may be that in group-moderate, the participants still maintained adequate oculomotor control and functional visual field, so that distance and near acuity measures were still correlated. These findings suggested that the underlying pathology may be an important factor that influences reading performance, and that reading performance may be more related to the extent of the functional field of vision, oculomotor control, room luminance and/or glare sensitivity. For example, the group-mild was dominated by children with albinism (63%) compared to group-severe (13%) and group-moderate (18%) whose visual performance may therefore be more sensitive to glare. Previous studies have shown albinism is a contributing factor in decreased reading performance and is thought to be due to nystagmus and foveal hypoplasia (Merrill *et al*., 2011; MacDonald *et al*., 2012). Although there were no significant group differences between children with and without nystagmus, the severity of the nystagmus was not noted and may become greater under higher luminance or in stressful situations (Tkalcevic and Abel, 2003), which may have affected the reading performance in this sub-group.

Variations observed between the VI groups, based on VA, may be due to interactions of additional factors that can affect reading ability, such as convergence ability, Crowding Intensity, scanning ability, contrast sensitivity and the extent of the functional field of vision that have all been implicated in reading ability (Dusek *et al*., 2010; Falkenberg *et al*., 2007; Huurneman *et al*., 2016a), These findings suggest that a single measure of distance or near acuity cannot accurately predict the reading performance of each individual with a VI and therefore an assessment of functional reading ability should be a part of the clinical assessment for every children with a VI. This would help guide educators to ensure the optimal print size was used to maximise reading speed without a loss of comprehension.

Previous studies have all documented slower reading speeds in children with a VI (Bosman *et al*., 2006; Corn *et al*., 2002; Douglas *et al*., 2004; Gompel *et al*., 2004; Huurneman *et al*., 2016a; Lovie-Kitchin *et al*., 2001; Lueck *at al*., 2003;). However, this study has also demonstrated that reading speed is variable and cannot be predicted from a single measure of distance VA. This main finding highlights the importance of determining CPS for those with a VI. Lighting and glare levels also play a large factor in visual performance, particularly in people with low vision.

The visual performance of a VI student in a classroom may be dramatically changed by lighting levels, which can reduce or increase the symptoms of visual fatigue (Schakel *et al*., 2019). A student with cone dystrophy or albinism may be negatively impacted by a bright well-lit classroom, as opposed to a student with ONH who may need extra light to help differentiate detail with increased contrast. This difference in visual ability and the various pathological aetiologies, may have contributed to the variation in reading results obtained between the groups with glare and oculomotor control being the likely main factors that will require additional studies in a larger clinical population to verify. Based on these initial findings, a proposed framework to support children with a VI in reading would involve consideration of their underlying pathology, luminance, contrast of the text, their functional visual field and ocular motor control.

By adopting an integrated approach, children with a VI would be better supported in the classroom by ensuring font was at least as large as the CPS, and consideration of contrast, text polarity and room luminance are optimal, so that visual fatigue and an inability to engage with learning materials is minimised. Visual fatigue can be a significant issue for students with low vision, particularly at the end of a school day, which can impact self-esteem and quality of life (Decarlo *et al*., 2012; Schakel *et al*., 2019). Strategies that may help to reduce the impact of visual fatigue, such as increasing working distance, regular breaks from visually demanding tasks, encouraging an increase in outdoor play and the use of adaptive technology, may help the child perform more comfortably within the classroom. The use of relaxation techniques to cope with visual fatigue, such a listening to music and brief rest periods, may also provide additional methods to support these children (Schakel *et al*., 2019). The use of electronic devices that can easily enlarge font to a comfortable size and change contrast or reverse the polarity of text to white on black, can help to improve accessibility to reading materials (Loh *et al*., 2022).

These findings have highlighted that distance VA does not always correlate with the optimal print size requirements and depends upon, in part, the cause of the underlying VI. Thus, the standard clinical measure of distance VA may not always be adequate to determine the best font size requirements for children with a VI. Additional measures of near reading ability could assist educators to provide appropriate modifications to text size and contrast to fully support the child. Considering the range of other factors that affect reading performance, such as pathology, contrast sensitivity, Crowding Intensity, scanning ability, impact of lighting levels and the presence of nystagmus, is imperative to provide the ideal environmental conditions for a student to work in a classroom at their optimum capacity. Further work will be needed to determine whether educational outcomes can be improved by adopting a more individual and holistic approach to assess reading performance in children with a VI. Investigating print size requirements in adults with a VI resulting from glaucoma or macular degeneration would also be beneficial to help adults optimize their work productivity and improve their QOL.

4.3.4 Relevance to Research Questions

Research Question

This section of the thesis aimed to address the following research question:

- How do standard Visual Function measures, such as VA, portray the functional state of vision from students with a VI?

It aimed at addressing the research question “does visual acuity represent functional vision”. It was designed as a direct comparison of vision function based on VA, and functional ability (reading performance). The results showed that distance VA, a measure of vision function, is a poor indicator of reading ability in students with a severe or mild VI, particularly in terms of print size requirements. It highlights that further functional measures are required to adequately support a student through education.

The findings also highlighted that the assessment of reading print size requirement should be on an individual basis since the distribution of results on the scatter plots indicate a large degree of variability, warranting an investigation of reading font size requirements performed on each individual student independent of distance VA measures.

4.4 Maximum Reading Speed

Reduced reading speed can have a significant impact on a child learning in a classroom environment. Reading is a fundamental skill that serves as a gateway for accessing information and acquiring knowledge. Education is heavily weighted towards reading ability that is required to access information.

When a student reads at a reduced rate, due to a VI, it can lead to difficulties keeping up with class work, assignments, and tests. These individuals may then have difficulty completing work in the same timeframe alongside their normally sighted peers within the classroom environment. This could lead to decreased confidence, frustration, and impact motivation within the classroom.

The following section of the thesis investigated the MRS of students with a VI within South Australia and compared them with age-matched reference MRS of students with normal vision using the MNREAD test.

4.4.1 Introduction

For students with a VI, access to classroom content and educational outcomes can be negatively impacted by their VI, which can reduce their long-term social and economic standing (Decarlo *et al*., 2012; de Verdier and Ek, 2014; Gilbert, 2001).

Several studies have investigated the impact of uncorrected refractive error and the detrimental impact it has on classroom performance. White *et al*., (2017) found that in a sample of 109 Grade 3 students in Queensland, Australia, 30% failed vision screening, with these students referred for further vision testing scoring lower on national standardised testing. Using simulated hyperopia, Narayanasamy *et al*., (2014) found that even small levels of hyperopia reduced reading rate, accuracy, and comprehension, and impacted visual processing and reading-related eye movements (Narayanasamy *et al*., 2014). These results were replicated when they simulated an astigmatic error, supporting the need for clear vision that is appropriately corrected for the visual task (Narayanasamy *et al*., 2015). For students with a VI, and therefore uncorrectable VA less than 0.50 logMAR (6/12), additional requirements in the classroom are required to provide an equitable environment to ensure that these students can read and work at the same rate as their normally sighted peers.

Learning to read requires developing word-decoding skills, or the capacity to recognise individual words and understand the written text through a knowledge of grammar and syntax (Ehri, 2009). An increase in reading speed indicates normal reading attainment with speed typically increasing throughout typical development and educational levels (Lobier *et al*., 2013). Age is therefore the strongest predictor of reading rate, and maximum reading rate is usually obtained by the end of secondary school (age ~18 years), where it then stays constant until a slow decline later in life with ageing (Calabrèse *et al*., 2016; Lovie-Kitchin *et al*., 2001). Students with a VI learn to read using the same phonological methods as students who are normally sighted, but their reading speed is slower and limits their ability to learn at the same rate as students with normal vision (Bosman *et al*., 2006; Douglas *et al*., 2004; Gompel *et al*., 2004).

Corn *et al.,* (2002) investigated reading rates in children with low vision and identified key year levels at which students were at greater risk of developing poorer literacy skills. Students with a VI had slower reading rates than their peers through grades two to six but maintained the same lag in reading rate as students with normal vision. However, by grade 6 (aged ~ 10-11 years) the gap widened and the difference in reading rates between students with a VI and their normally sighted peers increased significantly. This was presumably due to several factors. At year six, school workloads increased as students prepared for the transition to secondary/high school. Additionally, as workloads increased, sufficient time may not have been given to a student with a VI to complete their work, resulting in visual fatigue and poorer reading (Schakel *et al*., 2019). In addition, social factors may also affect these students as they approach an age where they are reluctant to appear different to their peers at school and therefore may not fully accept support that is offered so as not to appear 'different' (Khadka *et al*., 2012). A qualitative study of students from mainstream high schools in Victoria, Australia found that students expressed the desire for extra time to complete work and had difficulties accessing work, which made completing class work more time consuming (Opie *et al*., 2017). If a student with a VI can read at only half the speed as their peers within a classroom, then they will require approximately twice as much time to complete the same reading related task or assignment. Therefore, the ability to assess and provide the optimum conditions for a student with a VI to read, would allow teachers to tailor specific requirements to enable the student to achieve their maximum learning potential.

This study investigated the oral reading rates of a cohort of students with a VI using the MNREAD application that measures reading performance using digital text as detailed in **Chapter 4.2**. Reading performance was compared to previously published data in students with normal vision (Calabrèse *et al*., 2016). In addition, several narrative reflections are reported from students, which provided an insight into the difficulties these students with a VI experienced whilst accessing educational materials in their classroom.

4.4.2 Methods

Participants

A total of forty-seven VI participants, 28 male and 19 female were eligible for analysis of oral reading rates, with recruitment previously discussed in Chapter 4.1. Ages ranged from 8-16 years of age (mean 11.9 ± 2.4 years) and school grades ranged from reception to year 12 (6.0 ± 2.5).

In this study group, the most common causes of VI were retinal dystrophies (n=16), followed by albinism (n=13). Seven students had optic nerve abnormalities, two had ROP, and one student each with aniridia, iris/choroid coloboma, uveitis, retinal detachment, congenital glaucoma, or congenital cataracts as the cause of their VI. Idiopathic infantile nystagmus was diagnosed in three of the students, with nystagmus secondary to the underlying disease present in 83% of the VI participants.

Reading Performance

The MRS was evaluated using the MNREAD as previously described for the assessment of reading print size requirements in **Chapter 4.3**. The sentence display was controlled by the examiner to ensure accurate timing from the display of the sentence to the completion of reading. Subsequent sentences become progressively smaller until the student could no longer see the print at the testing distance, or they made more than 10 errors reading the sentence. A trial test was performed to familiarise the student with the test, then different sentence sets were used to avoid memorisation, and an average of reading speeds calculated for 2 trials. For details see section see **Methods, Chapter 3.3.1**.

Once a student was unable to read the print or made more than ten reading errors (inability to see word, mis-read), the test was stopped by the examiner and the results were displayed on the iPad screen. The results included the: MRS in WPM, reading acuity (the smallest font that could be read) in logMAR and the CPS (the smallest font that could be read at the MRS in logMAR) see **Methods, Chapter 3.3.1** for details.

Statistics

MRS for each age were compared with published reference data for students with normal vision. Relationships between age and MRS were evaluated using Pearson's correlation coefficient. All analyses were performed using IBM SPSS version 28 (IBM, California, Santa Barbara). All values are reported mean ± standard deviation unless otherwise stated.

4.4.3 Results

Maximum Reading Speed

The MRS for students with VI was 75.9 ± 20.3 (range 40.0 to 97.6) WPM. Normal vision MRS based on those reported by Calabrèse *et al.,* (2016), which was collected from 110 children and teenagers in Minneapolis, USA were 166.5 ± 21.8 (range 137 to 202) WPM, with comparison by age shown in **Table 4.6**.

Table 4.6: Maximum reading speed for each age group

	Maximum Reading Speed (words per minute)	
Age (male:female)	**Vision Impairment**	**Normal Vision**
8 (3:3)	82.0 ± 20.2	137 ± 13
9 (1:2)	40.0 ± 18.3	145 ± 13
10 (2:1)	72.3 ± 53.9	153 ± 13
11 (4:3)	51.4 ± 28.3	161 ± 13
12 (5:3)	85.7 ± 27.4	170 ± 10
13 (4:3)	93.3 ± 42.5	178 ± 10
14 (5:3)	85.0 ± 31.6	186 ± 10
16 (2:3)	97.6 ± 43.4	202 ± 10

Table 4.6. Maximum reading speeds for each age. Age in years with number of (male:female). Maximum reading speeds ± standard deviation (words per minute) of students with low vision and normal vision based on reference ranges reported by Calabrèse *et al.*, (2016).

Figure 4.9: Maximum Reading Speed and Age

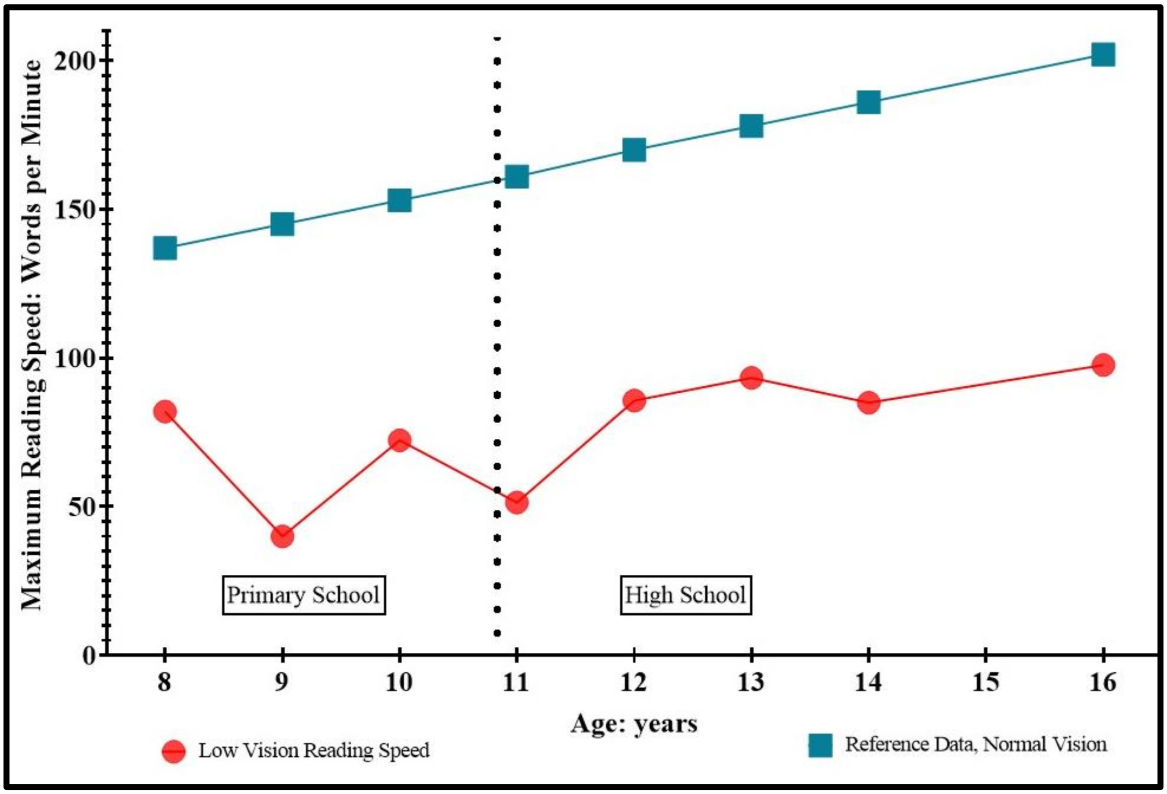

Figure 4.9. Plot of the relationship between maximum reading speed and age, with green squares indicating the reading speed of students with normal vision based on data from Calabrèse *et al.*, (2016a) and replotted. The red circles show students with VI in this study. The divergence in maximum reading speed from age 11 years (dotted line) to the completion of school at age 17 years, between the groups is apparent.

There was also a larger variation in reading speeds for the students with VI (SD ranged from 18.3-53.9 WPM), compared with data from Calabrèse *et al.*, (2016a) in students with normal vision (SD ranged from 10-13 WPM). **Figure 4.10** replots the mean MRS with the SD of both groups to illustrate the wide SD in the VI group - however all those with a VI never achieved the same MRS as a normal sighted individual throughout their school years.

Figure 4.10: Maximum Reading Speed with standard deviation for age

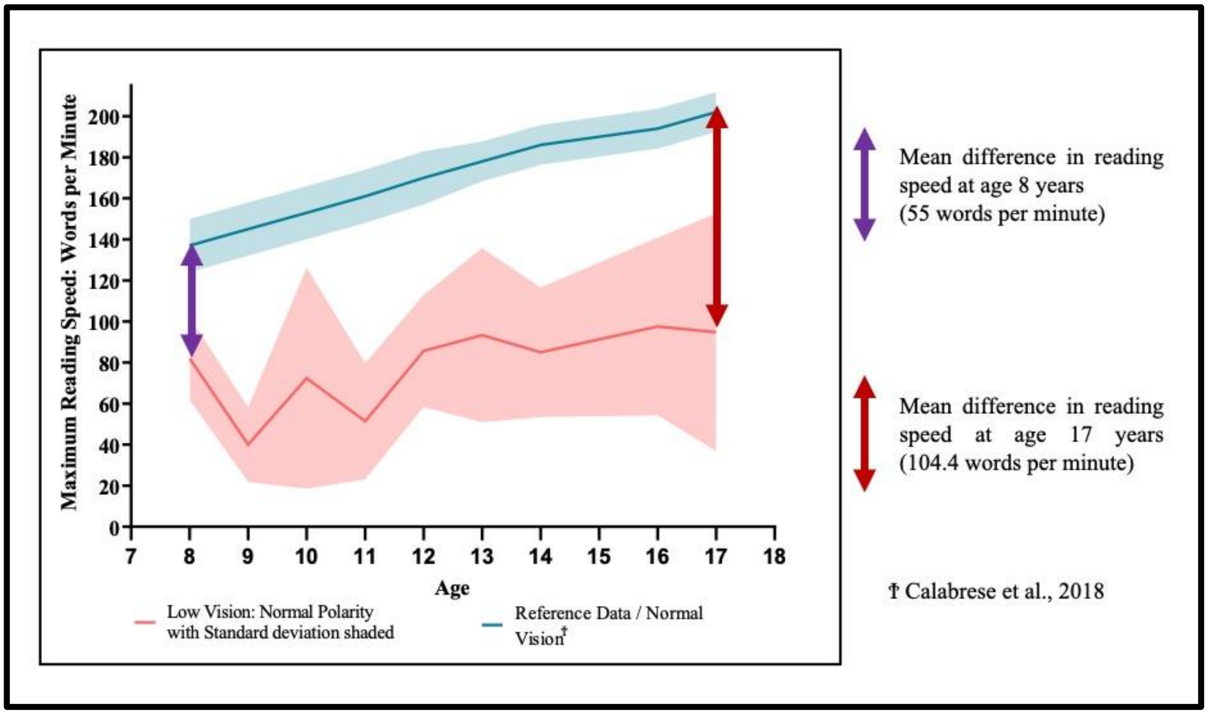

Figure 4.10. Maximum Reading Speed and age (years), with shaded areas indicating two standard deviations from the mean. This plot shows that despite the large variation in maximal reading speed of the VI group there was no overlap with the maximal reading speeds in normally sighted children of the same age throughout the school years.

Regression Analysis

There was a weak but non-significant positive correlation between age and MRS, with an increase in age indicating an increase in MRS (p=.06, r^2= 0.02) as shown in **Figure 4.11**.

Figure 4.11: Scatter Plot of Maximum Reading Speed and Age

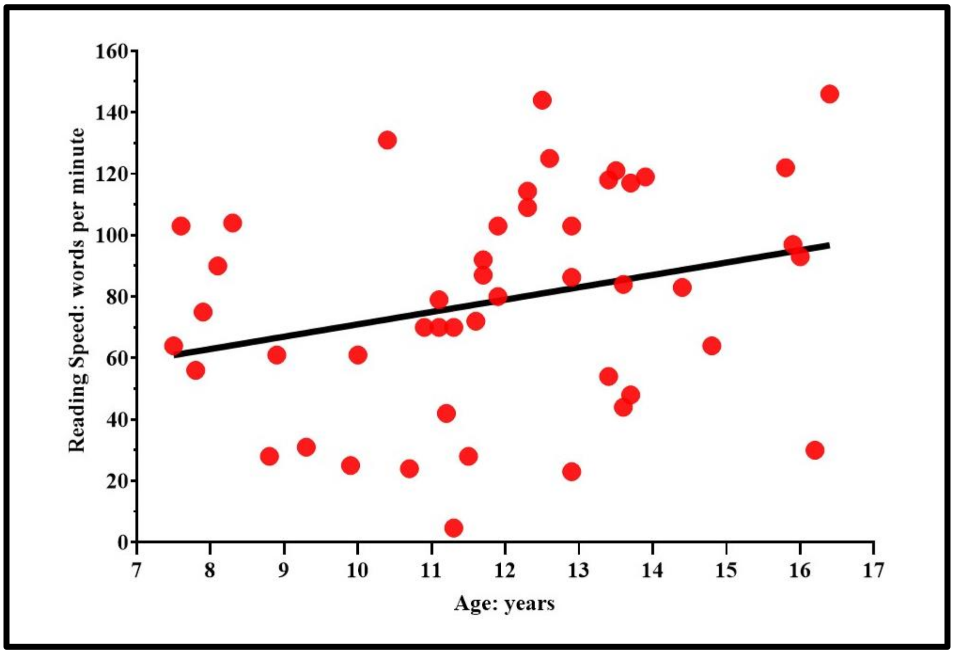

Figure 4.11. Correlation of age (years) with maximum reading speed (words per minute) in participants with a VI. There was a positive but non-significant relationship (*p*=.06, r^2=0.02) highlighting the variability with maximum reading speed and age in the participants with a VI.

4.4.4 Reflections During the Reading Assessments

While completing the reading assessments, the students with a VI remarked about their difficulties working alongside their normally sighted peers at school. The students with a VI commonly expressed the need for extra time to complete their assignments and teachers were generally very good at accommodating these requests. However, several of the students with a VI identified that difficulties occurred when teachers either did not know them, understand their vision, or if there were relief teachers. Comments included:

> ***"I don't like relief teachers; they don't understand my vision."***

(Year 8 male student)

With a relief teacher reported asking:

"Why do you wear sunglasses in class when there is no sun?"

Students mentioned that it could be hard to finish work in class time and used empty study lines to try and complete work that they were unable to do in class, so they would not have extra work to do at home.

"I'm too tired when I finish school and I have headaches most days."

(Year 10 female student)

Visual fatigue can be a limiting factor for a student with a VI and when combined with reduced reading speeds, also results in difficulty completing work at the same rate as their peers. Even with extra time allowances, some students noted that they were only able to work for short periods before becoming tired from visual fatigue.

"I can only read for about 20-30 minutes before my eyes get really tired and blurry."

(Year 9 female student)

Students mentioned that they often asked for extensions for assignment deadlines. Tiredness, sore eyes, and headaches at the end of the day were commonly reported by the students.

"If I'm really struggling, I use audio text – but I don't like doing it, or I just sleep."

(Year 7 male student)

Several students mentioned that having work in advance helped them to be productive during class time. Being able to read content before the class, in their own time, allowed them to be prepared and they felt they were not having to try to continually keep up.

> ***"I prefer to read classwork in advance, so I know what I'm doing, and it makes the class less stressful, but sometimes teachers forget to give it to me."***
>
> ***(Year 9 male student)***

Exams and stress can also impact working time for students with a vision impairment and exacerbate visual fatigue (Schakel *et al*., 2019). Students also mentioned that despite getting extra time they often struggled with written exams.

> ***"I never seem to have enough time in exams."*** and ***"I tend to panic."***
>
> ***(Year 11 female student)***

4.4.5 Discussion

The main findings of this part of the thesis were the demonstration of a significantly reduced MRSs of students with a VI across all ages compared to an age equivalent normative range. In addition, the VI group had large MRS SDs with no individual attaining an equivalent age matched MRS of the normally sighted group data. Taken together, these results support the role of reading speed in the results of Corn *et al.*, (2002) who showed lower literacy skills in children with a VI and this disparity increased around the age of 11-12 years at the commencement of high/secondary school when reading speed also fell away in this VI study group. At the start of primary school (age 8 years), the difference between mean MRS was 55.0 WPM, and towards the end of high school at age 16 years, the MRS difference had increased to 104.4 WPM, indicating greater disparity in reading speed between the groups as educational demands increased.

The initial lag in reading speed at age 8 years may be due to delayed early literacy skills, which play a significant role in the development of reading ability (Purpura *et al*., 2011), which in turn is a reliable predictor of future academic success (Butler *et al*, 1985; Cooper *et al*., 2014). Early literacy begins before formal schooling commences, through exposure to literacy in a social context (Whitehurst and Lonigan, 1998). It is possible that in those with a VI, their slower reading rate is due to delayed exposure to early literacy skills.

Although age and reading speed demonstrated a non-significant correlation (p=0.06), age is a good predictor of reading speed, and typically reading speed increases with age throughout school years as reading ability develops (Lovie-Kitchin *et al*, 2001). MRS is usually obtained by the end of secondary school and stays constant until there is a slow decrease after forty years of age (Calabrèse *et al*., 2016). Given there was not a strong positive correlation between reading speed and age in the VI group suggests that the typical trajectory of increased reading speed with age is more variable in this group and does not follow the typical trend observed in normally sighted children as demonstrated by the increasing divergence in MRS observed across the age groups. This discrepancy is most likely due a combination of factors including poor VA, reduced oculomotor control and reduced access to reading materials during early development. Further research is required with a larger sample size to investigate the reasons behind this discrepancy.

MRS is an important factor for students within a classroom, whose work is predominantly based around near vision tasks (Narayanasamy *et al*., 2016). A reduced reading speed for these VI students compared to their normally sighted peers is likely to have a negative impact on their classroom learning and ability to keep up with reading material. However, due to the large variation in reading rates within age levels, it also makes it very difficult to provide generalised guidance as to time requirements for VI students based on their age, and therefore each student's MRS should be determined on an individual basis. This approach would enable a determination of the CPS to ensure most efficient reading speed and the MRS to determine the likely extra time that might be required to read a set text on a case-by-case basis.

From the concerns that students voiced during the assessments regarding sufficient reading time and visual fatigue, an individualised support approach and specific tailored guidelines are more appropriate to ensure the best and most equitable opportunities for children with a VI to access their reading materials in the classroom. Further studies could also investigate how MRS might vary at different times of the day or week, and in different situations for students with a VI such as during an examination when they are under additional stress. Comparing reading performance at the beginning and end of a school day, and at the end of the week, could give further information surrounding the effects of visual fatigue on the VI individual's reading performance during the school day and the impact during a school week. This in turn may inform teachers of the best way to approach homework or assignment requirements, or suggest alternative ways to complete work, such as using audio technology or dictation. Assessment of reading speeds around exam time may also provide insight into the effect of stress on reading ability and help to provide more appropriate support for these students during these assessment periods. In addition, eye tracking studies and letter spacing for VI students may offer further details about the way a student with a VI reads text and the impact of letter spacing on their MRS and overall reading efficiency.

4.4.6 Conclusions

Determining reading ability and enhancing support for students with a VI at an early age is crucial to support their foundations for future learning at school and potentially prevent the widening of the reading lag that occurs before the transition to high school. MNREAD is a fast, simple test that can be used to determine reading speeds for all students with a VI from age 8 years. Implementing a reading assessment would provide insights to enhance support, by providing individualised accommodations that would allow for a greater accessibility for these students in the classroom. Enhanced knowledge of optimum reading conditions (reading speed, font size) would provide a students' teachers and support team, the ability to tailor these requirements to achieve maximum learning potential for each student.

4.4.7 Relevance to Research Questions

An increase in reading speed with age is a normal development in children. During early childhood children learn to read by initially recognising individual letter sounds and simple words, as their skills develop over the course of schooling, reading becomes more proficient and reading speed increases. This section of the thesis established that students with a VI have an improvement in reading speed with age, but at a reduced and more variable rate than normally sighted children. It also confirmed previous findings that the gap between the reading speeds of students with a VI and students with normal vision widens throughout school years, leading to a significant lag in reading speed between students with a VI and students with normal vision by the time they reach the end of their schooling.

4.4.8 Visual Acuity and Maximum Reading Speed

Distance VA measures were also correlated against MRS as shown in **Figure 4.12**. There was a significant correlation of distance VA with reading speed, both with NP (p=.001, r^2=0.25) and RP font (p=.003, r^2=0.17) showing a reduction in reading speed with reducing distance VA. However, the scatter plot shown in **Figure 4.12** revealed a large variation in reading speeds across VA levels. This variation in reading speeds exhibit the same profile as the variability observed between age levels for reading speed and reemphasises the need for an individualised assessment of reading speed for VI students to provide suitable time adjustments for reading tasks in the classroom.

Figure 4.12: Visual acuity and reading speed

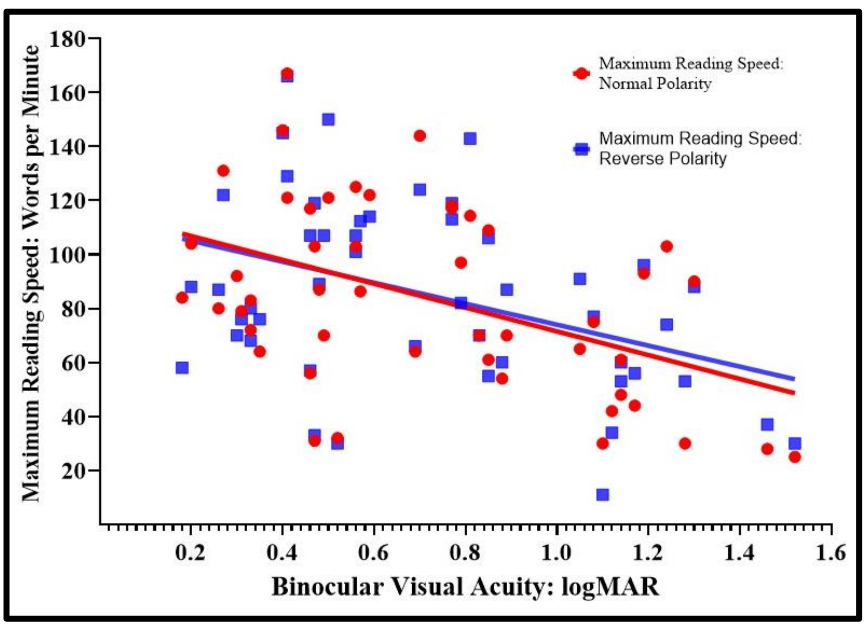

Figure 4.12: Relationship between distance visual acuity and maximum reading speed in normal polarity (red circles) and reverse polarity (blue circles). There was a significant negative correlation in both cases with maximum reading speed decreasing with reduced visual acuity (p<.003).

4.5 Reverse Polarity Text

When text polarity is reversed so that white text is displayed on a black background, there is reduced luminance and potential glare from the display. Because of this, RP is often used in car dashboards for night-time driving despite evidence that NP or positive polarity text is more legible (Buchner *et al.*, 2009; Pipenbrock *et al*., 2013). However, in the presence of cataract with poor transparency of the ocular media, RP, or negative polarity text improves reading performance individuals with a VI, presumably due to the reduced glare (Legge *et al*., 1992).

In this section of the thesis, the impact of RP on the reading performance of students with a VI was explored, focusing on two key metrics: MRS and CPS by comparing the difference in participants using NP compared to RP reading material. The difference in reading performance for the NP and RP conditions were then compared with functional retinal cone responses using the 30Hz flicker ERG amplitude. The difference in reading performance using NP to RP were also compared based on the underlying pathologies to determine if there were any characteristics that influenced reading performance.

This section of the thesis contains work currently under review with Clinical and Experimental Optometry.

"The impact of using reverse polarity text for children with a vision impairment." Loh L, Prem-Senthil M, Constable PA.

One previous study by Legge *et al.,* (1992) with *n*=141 participants with ages ranging from 14-96 years (mean 51±22.7) with a VI, compared the effect of RP print on individuals with clear or cloudy media. If there was any evidence of corneal scarring, cataract, or vitreous debris, the ocular media was identified as "cloudy" (*n*=45), otherwise it was identified as "clear". They found that individuals who preferred the RP text did so because they were impacted more by glare and light scatter from cloudy media more apparent in the NP text. Based on this observation it may be that children with a pathology that makes them more susceptible to glare, such as albinism or cone dystrophy, would benefit more from RP text by reducing the large glare source associated with the white background in NP (or positive polarity) text. This part of the thesis investigated this hypothesis.

Written material is generally presented as NP which increases the legibility of text - termed the 'positive polarity' advantage (Dobres *et al*., 2017). The mechanism is believed to be due to a constriction of the pupil as the overall illuminance is higher and decreases spherical aberrations giving a clearer retinal image (Piepenbrock *et al*., 2014). One study reported that when screen luminance was kept constant by controlling text and background illumination so that pupil size was constant for either RP or NP text, then the 'positive polarity' advantage was not apparent, supporting the hypothesis that miosis and reduced spherical aberrations contribute to better reading performance with normal polarity text (Buchner *et al*., 2009).

To further assess the impact of RP digital, and paper-based print on reading performance in children with a VI, this section examined changes in reading performance based on clinical diagnosis and visual function. This was to ascertain if changes in text polarity would impact reading performance based on clinical measures of binocular distance VA, contrast sensitivity (logCS), flicker ERG amplitude and pathological cause of VI.

4.5.1 Methods

Participants

Participants for this study were recruited as previously described in **Chapter 3.1**.

Due to nystagmus and difficulty maintaining fixation, extreme glare sensitivity (particularly for Flicker ERG measures), or non-compliance, not all tests of visual function were completed on all children with a range of 23-43 measures completed across the categories. Participant numbers for each test are detailed in the results section (Chapter 4.5.2 and Table 4.7)

Visual Function

Binocular VA (logMAR), contrast sensitivity (logCS) and light adapted 30Hz flicker ERG amplitude were measured using the methods described in **Chapter 3.2**.

Reading Performance and Text Polarity

Digital Material

Digital reading performance was assessed using the MNREAD, as previously described in **Chapter 3.3.1**. All measures were performed using NP (black on white) and RP (white on black) Times New Roman print. Each measure of MRS and CPS was recorded for normal then reverse polarity with the change in digital reading performance measures (ΔCPS and ΔMRS) defined as the difference between the normal minus the reverse polarity condition. **Figure 4.13a** illustrates a participant reading RP text generated by the MNREAD application on the iPad.

Paper Material

Printed material using 24-point Times New Roman text on high contrast A4 black on white (normal) or white on black (reversed) matte laminated cards were used to evaluate Number Reading Speed (NRS) based on the design of the Horizontal DEM test (Ayton *et al*., 2009). Details of the test procedures are detailed in **Chapter 3.3.2**. The test cards are shown **Figure 4.13b** with the participants with a VI instructed to read the numbers aloud and horizontally from left to right, as quickly and accurately as possible. The time taken to read every number on the card was recorded with an electronic stopwatch with one second added for any incorrectly read numeral. Two practice runs were allowed with different number cards prior to the timed test to minimise any learning effects. The change in numerical reading speed (ΔNRS) (normal minus reversed) was calculated in seconds with the normal polarity always presented first. A lower numerical value of time indicated an improved performance as the participant was able to read the numbers on the card at a faster rate.

Figure 4.13: Text polarity using screen and printed material

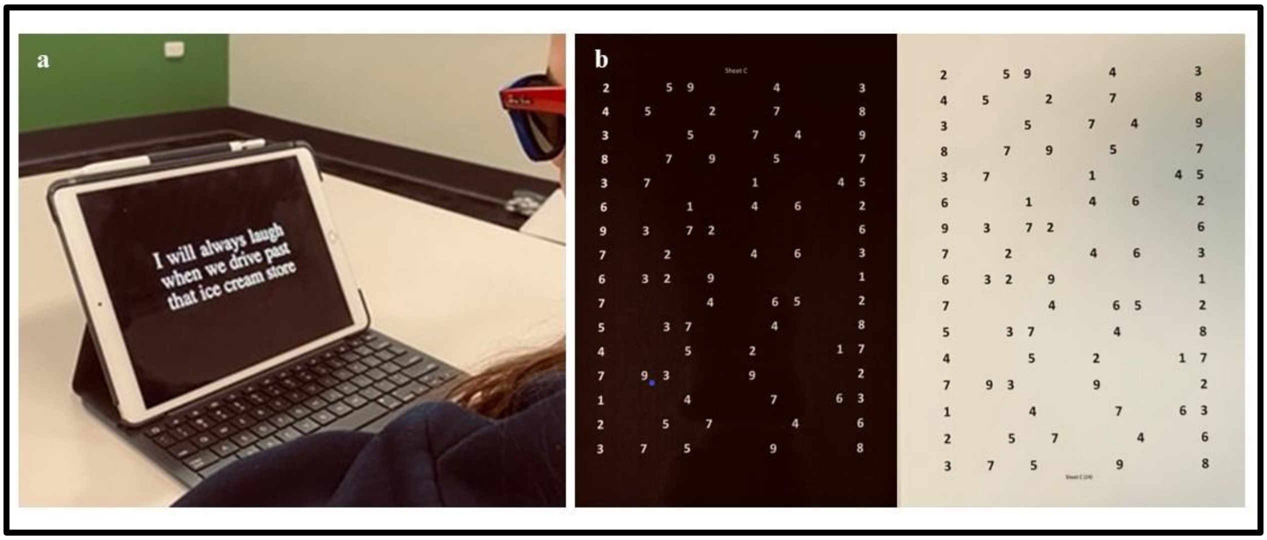

Figure 4.13. (**a**) A participant reading the reverse polarity digital text using the MNREAD platform on an iPad. The participants were asked to read aloud as quickly and as accurately as possible until they could no longer see the text or made 10 or more errors in their reading. (**b**) Printed laminated matte A4 cards with reverse polarity numerals (N24 Times New Roman) with 16 lines with 1.5 line spacing and 5 random numerals per line. The participant was instructed to read from top to bottom left to right as quickly and as accurately as possible. The time taken was recorded using a stopwatch in seconds, with a second added to the total time for each misread numeral.

Statistics

Statistical analyses were performed using SPSS Version 28.0.1 with Pearson correlation coefficients used to determine the relationships between reading performance and functional vision parameters. For paired data the effects of reading performance between NP and RP were assessed using the Wilcoxson paired signed ranked test.

4.5.2 Results

Reading performance and visual function

When the changes in reading performance (ΔMRS, ΔCPS and ΔNRS) were correlated with measures of visual function (VA, contrast sensitivity (logCS) and the 30Hz flicker amplitude), there were only significant relationships between the 30Hz flicker amplitude and the changes in reading speed for digital and paper-based reading performance as shown in **Table 4.7**. The ΔMRS and ΔNRS were 1.0 ± 14.8 WPM with range +37.0 to -29.0 WPM and 0.3 ± 4.9 seconds with range -8.29 to +14.3 seconds respectively. The ΔCPS was 0.01 ± 0.1 logMAR with range -0.4 to +0.4 logMAR. There was a significant negative correlation between ΔMRS (p=.028, r^2=.18) and ΔNRS (p=.027, r^2=.21) with the 30Hz flicker amplitude (**Table 4.7**, **Figures 4.14** and **4.15**).

In contrast, there were no significant correlations between high contrast distance VA or contrast sensitivity with any measures of reading performance (p>.21).

Table 4.7: Reading performance and vision function

	30Hz amplitude	**Binocular VA**	**Contrast Sensitivity**
ΔMRS	n=27, $\mathbf{p}$**=.028**, r^2=.18	n=48, p=.38, r^2=.02	n=47, p=.69, r^2=.003
ΔNRS	n=23, $\mathbf{p}$**=.027**, r^2=.21	n=32, p=.21, r^2=.05	n=31, p=.29, r^2=.04
ΔCPS	n=27, p=.38, r^2=.03	n=48, p=.99, r^2<0.001	n=47, p=.45, r^2=.01

Figure 4.7. Pearson correlation coefficients and significance levels, for changes in mean reading speed (ΔMRS), critical print size (ΔCPS), and numerical reading speed (ΔNRS) between normal

and reverse polarity text with measures of visual function: (30Hz flicker amplitude, high contrast visual acuity (logMAR) and contrast sensitivity (logCS). Significant correlations between ΔMRS, (*p*=.028) ΔNRS (*p*=.027) were present with the 30Hz flicker amplitude). No other significant relationships were observed for the remaining parameters (*p*>.21).

Figure 4.14: Change in maximum reading speed and 30Hz amplitude

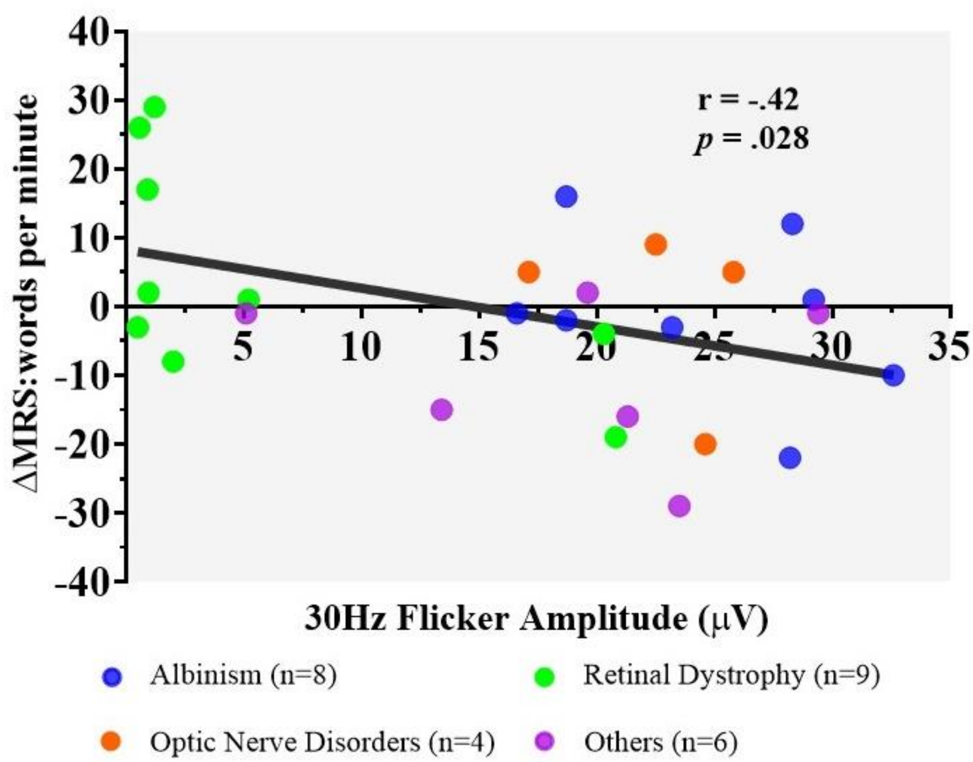

Figure 4.14. Change in maximum reading speed (ΔMRS) between digital normal and reverse polarity text and the 30Hz flicker amplitude. A significant negative correlation (*p*=.028) was found indicating that reduced retinal cone function was associated better performance when the print polarity was reversed to white on black.

Figure 4.15: Change in numerical reading speed and 30Hz amplitude

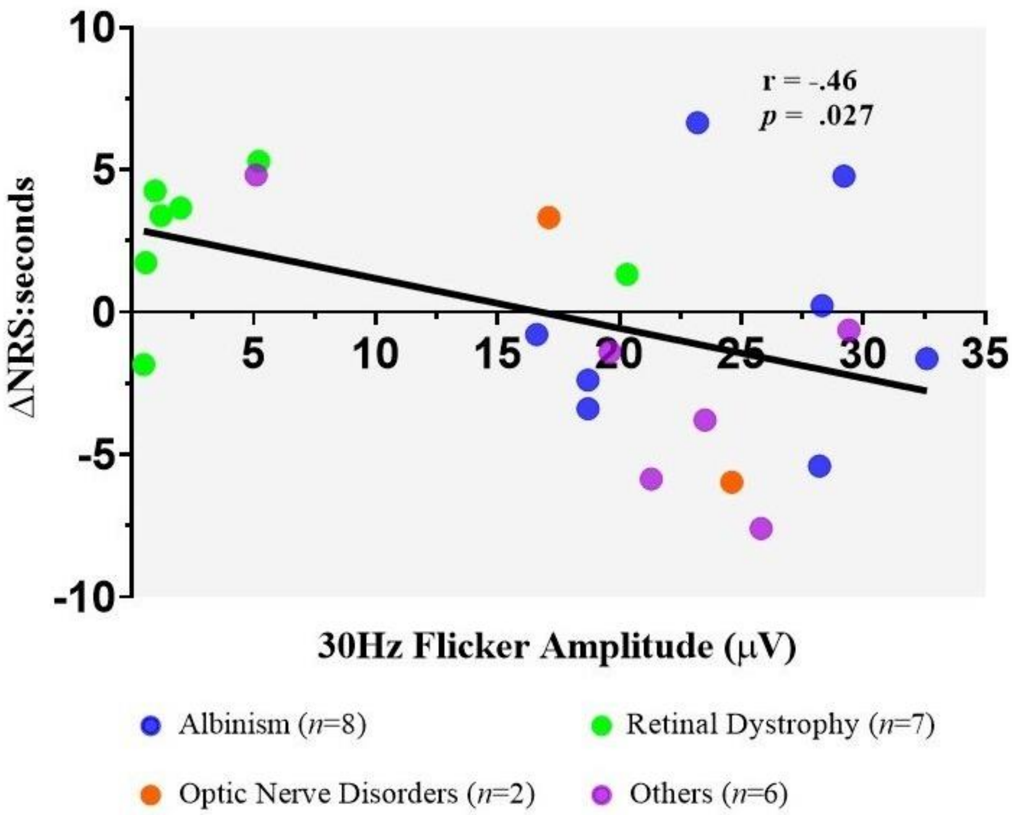

Figure 4.15. Relationship between change in paper based numeric reading speed (ΔNRS) and the 30Hz flicker amplitude as a measure of cone function. A significant negative correlation (*p*=.027) was found indicating that reduced retinal cone function was associated with better numerical reading speed on printed material when it was reversed to white on black.

Reading performance with text polarity and cause of vision impairment

Pairwise comparisons between NP and RP for the participants showed no significant differences with digital text (*n*=48): CPS (z=.01; *p*=.99) and MRS (z=.31; *p*=.76) or printed numerical text (*n*=32): NRS (z=.42; *p*=.67). The differences in reading performance (*n*=48) were for CPS:

0.01±0.14 (range -0.40 to +0.40) logMAR and for the MRS: 1.0±14.8 (range -29.0 to +37.0) WPM and for NRS (*n*=32)*:* -0.3±4.9 (range -8.4 to +14.3) seconds.

Follow up pairwise comparisons based on pathological group for the measures of reading performance only showed a significant effect of the retinal dystrophy group and CPS as shown in **Figure 4.16** with (*n*=12, z=-2.24, *p*=.025). All other pairwise comparisons based on group were not significant (*p*>.05). See **Table 4.8** for details and **Figures 4.16** to **4.18** that illustrate the mean changes in reading performance measures based on pathological group (albinism, retinal dystrophies, optic nerve disorders or other) as described in methods **Chapter 4.1**.

Table 4.8: Table of reading performance measures by pathology grouping

	Albinism	**Retinal Dystrophies**	**Optic Nerve Disorders**	**Other**
MRS	*n*=14, z=.53, *p*=.59	*n*=12, z=.94, *p*=.35	*n*=10, z=-.83, *p*=.41	*n*=12, z=-.39, *p*=.69
NRS	*n*=10, z=-.70, *p*=.48	*n*=7, z=-1.95, *p*=.051	*n*=7, z=-1.44, *p*=.15	*n*=7, z=-0.21, *p*=0.83
CPS	*n*=14, z=1.54, *p*=.12	*n*=12, z=-2.24, ***p*=.025**	*n*=10, z=-.55, *p*=.58	*n*=12, z=0.60, *p*=0.55

Table 4.8. Results of Wilcoxson pairwise signed ranked test of significance for reading performance measures: Maximum Reading Speed (MRS) Number Reading Speed (NRS) and Critical Print Size (CPS), and group based on primary pathology. Individuals with a retinal dystrophy performed significantly better on CPS with reverse polarity print, demonstrating smaller font size requirements (*p*=.025). No other significant differences were found for changes in reading performance from normal to reverse polarity text by pathology (*p*>.05).

Figure 4.16: Mean change in critical print size with pathology group

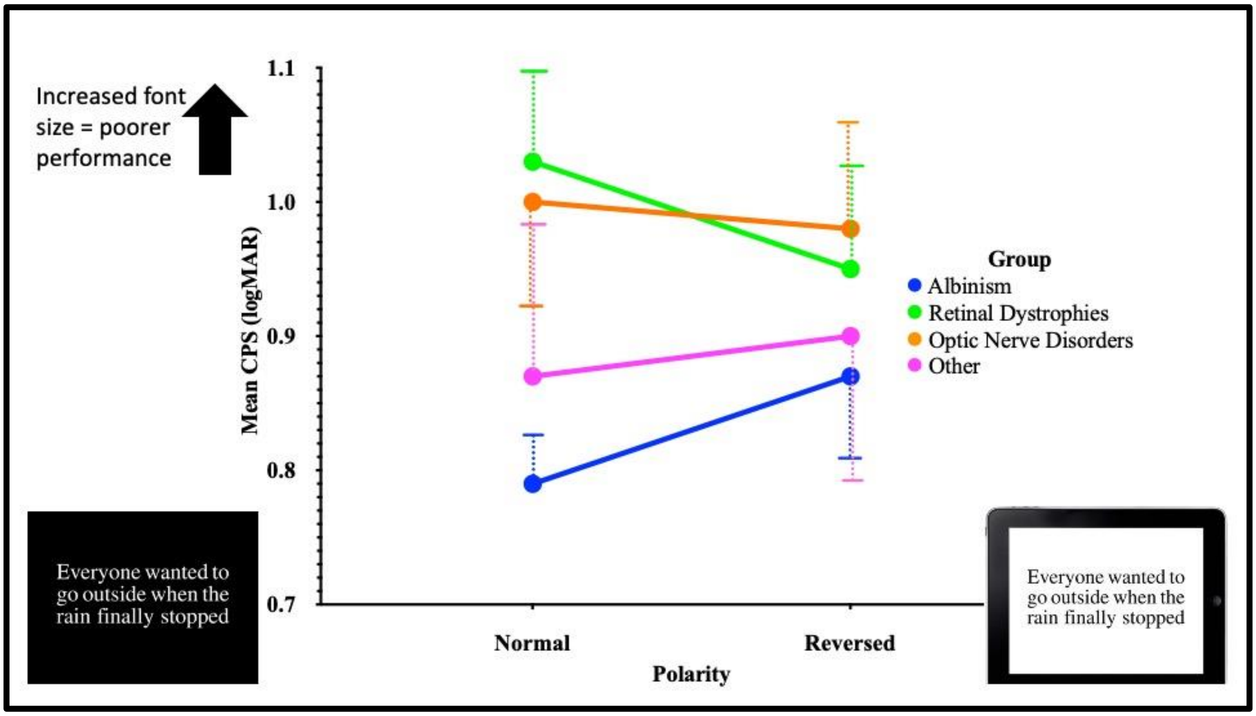

Figure 4.16. Change in Critical Print Size (ΔCPS) that could be read on an electronic device. compared with primary pathology. The Y-axis indicates the ΔCPS, with a larger value indicating the student required a larger font size between reading normal polarity (left of x-axis) and reverse polarity (right of x-axis) font. Albinism and the ’other’ group showing a mean increase in font size required indicating a poorer performance with reverse polarity text. In contrast, participants with a retinal dystrophy had an overall significantly (*p*=.025) better performance when using reverse polarity digital text. The dotted lines indicate the standard error of the mean.

Figure 4.17: Mean change in reading speed with pathology group

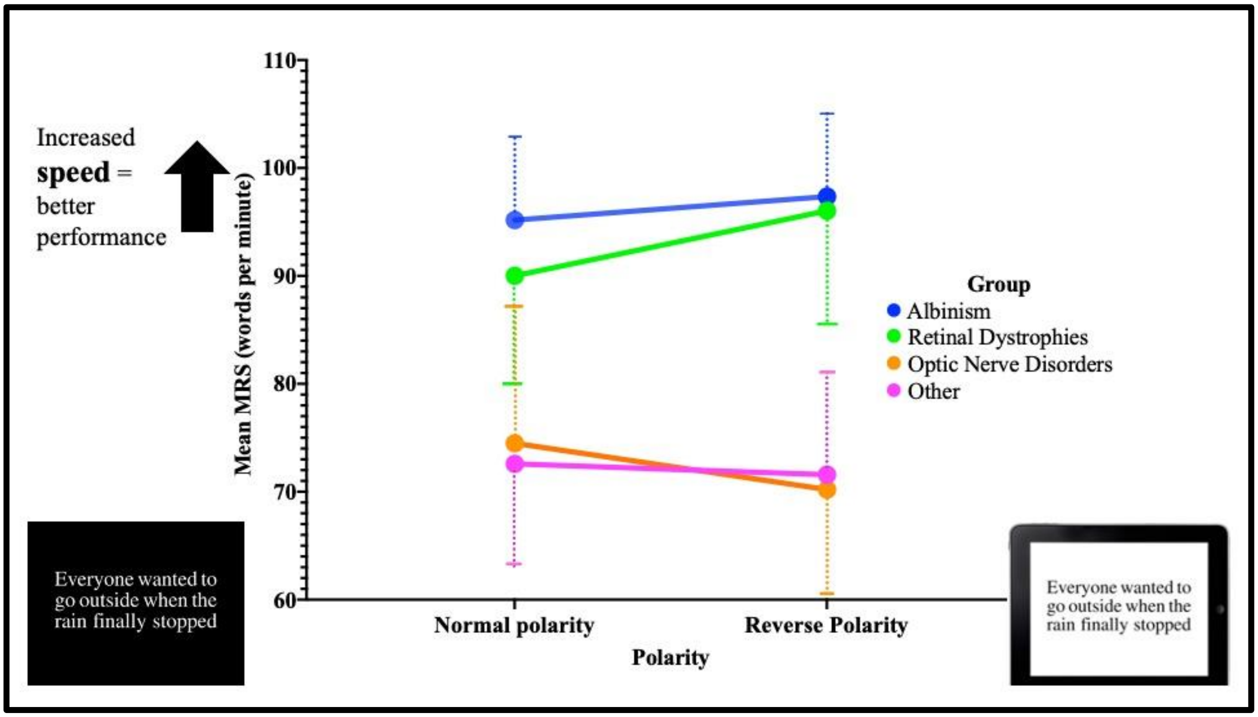

Figure 4.17. Change in mean Maximum Reading Speed (ΔMRS) between normal and reverse polarity in digital text compared with the pathology groups. The Y-axis indicates the ΔMRS, with a larger value indicating the student demonstrated a faster maximum reading speed between reading normal polarity (left of x-axis) and reverse polarity (right of x-axis) font. The albinism and retinal dystrophies group demonstrated a non-significant mean increase in the maximum reading speed whilst those in the optic nerve disorder or 'other' group had a slight decrease or no change in performance with the reversed polarity text. The dotted lines indicate the standard error of the mean.

Figure 4.18: Mean change in numerical reading speed with pathology group

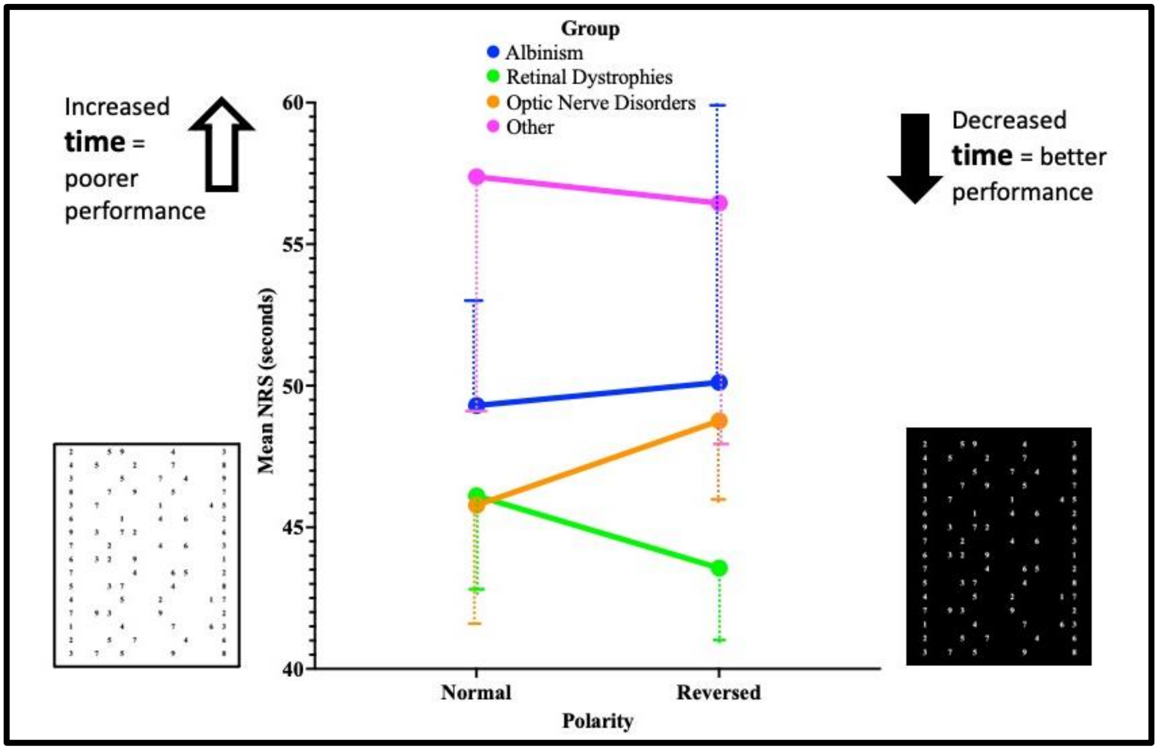

Figure 4.18. Change in mean Number Reading Speed (ΔNRS) between normal and reverse polarity text using printed numbers, compared with the pathology group. The Y-axis indicates the ΔNRS, with a larger value indicating the student took longer to read the numbers on the card between normal polarity (left of x-axis) and reverse polarity (right of x-axis). Albinism and optic nerve disorders demonstrating a mean increase in numerical reading speed with reverse polarity print whilst the retinal dystrophy and 'other' group had faster reading speeds on average with the reverse polarity printed numerical text. The dotted lines indicate the standard error of the mean.

4.5.3 Discussion

This part of the thesis reported the effects of NP and RP digital and printed reading material in school aged individuals with a VI. One of the aims of the section of the thesis was to determine if any measures of visual function could be used to identify individuals in this group that might benefit from reversing the polarity of their reading material. Of the measures of visual function, only the 30Hz flicker amplitude, that is a measure of retinal cone function had a significant ($p<0.03$) improvement in reading speed for digital and printed materials - that is those with poor cone function had improved reading speeds with RP digital and paper-based text. No other measures of vision function (VA or logCS) reached significance ($p>0.21$). Therefore, these standard clinical measures of distance VA and contrast sensitivity were poor predictors of any likely improvement in reading speed with RP print.

To further explore the possibility that improvements in reading performance may be linked to the underlying pathological cause of the VI, comparisons were made of reading performance by broad pathological group, using NP and RP text in digital or printed formats. Using printed material, those in the retinal dystrophy group demonstrated on average an improvement in MRS with RP printed numerals (+2.6 seconds). This mean improvement in MRS, just failed to reach significance (p=.051) which may have been due to the small number of participants (n=7) completing this task and a lack of statistical power. However, in the larger (n=12) sample of those in the retinal dystrophy group, there was a significant (p=0.025), improvement in the average CPS required to read when using RP compared to NP digital text. Taken together these findings suggest that those in the retinal dystrophy group may be more likely to achieve better reading performance when RP text is used. Although ΔMRS using RP text did not reach significance for any of the pathological groups (p>.35) there was a trend for mean faster MRS in those with a retinal dystrophy or albinism

, whilst MRS decreased, on average, for individuals in the group with either optic nerve or 'other' pathology group classification.

Participants included in the retinal dystrophy group did not require a larger font size with RP print, however those in the albinism or optic nerve disorder group did. The requirement for a larger font size with RP print corroborates previous research on electronic RP and individuals with normal vision, which showed that when RP displays are used (such as car dashboards at night), then a larger font size is required (Dobres *et al*., 2017; Piepenbrock *et al*., 2014). This is important when supporting students in the classroom because they may find a RP medium more comfortable to use, but depending on their underlying pathology, they may require a larger text size. This also suggests that the comfort benefit of using RP may be limited to electronic screen use for students with albinism and optic nerve disorder due to higher screen luminance levels, as the same advantage does not appear to exist with paper-based printed text.

In contrast, participants in the retinal dystrophy group did not need to increase text size to read faster and they also demonstrated faster MRS using electronic and paper-based material using RP text. One possible explanation could imply that, in addition to glare, other mechanisms contributed to the improvement in reading performance. The reduced, 30Hz flicker amplitude demonstrated that there was generalised retinal cone dysfunction and this was correlated with improved MRS on average when RP text was used for these groups. Using NP screen-based text would have a higher overall, screen luminance level than with RP screen, which would cause pupil constriction, resulting in a clearer retinal image due to reduced higher order aberrations (Wang *et al*., 2003). In a retinal dystrophy, however, particularly one that involves cone dysfunction, this may result in a deterioration in vision. It is also possible that a larger pupil is required to utilise an increased area of photoreceptor function due to an increase in cone spacing - as cone photoreceptor spacing is correlated with VA in individuals with retinal degenerations (Ratnam *et al*., 2013).

Photophobia caused by glare is a common finding in students with a VI and can lead to visual fatigue during the school day. Difficulties adapting to light may be due to increased light scatter in albinism, or a reduced adaptation time secondary to cone dysfunction, which may explain why some students with a VI prefer working under reduced room illumination (Loh *et al*., 2022; Schakel *et al*., 2019). Font displayed on an electronic screen using NP results in higher screen luminance levels than with RP. For students sensitive to glare, converting the screen to RP reduces retinal illumination and may consequently produce a more comfortable working medium for these students. Despite previous studies suggesting that glare is a predictor of increased reading performance with RP (Elliott *et al*., 1997; Legge *et al*., 1992) this study did not find that students with albinism demonstrated a significant improvement, although the sample was small.

Future studies are required to investigate other factors that may impact improved reading performance with RP, such as tracking eye movements and changes in pupil diameter with screen luminance. Of interest, four students with the largest increases in MRS with RP text all had manifest nystagmus, whereas the four largest decreases in reading speed with RP did not have nystagmus, supporting further work to explore the effects of ocular-motor control, and text polarity on MRS.

Further studies would also be warranted to investigate the role of the ON- and OFF- retinal pathways and retinal dystrophies. NP text stimulates the OFF-pathways as a dark letter stimulates the centre receptive field, which is surrounded by a brighter surround generating negative contrast, and RP text stimulates ON-pathways (Westheimer, 2007). Possible changes in these pathways in children with retinal dystrophies such as complete congenital stationary night blindness that is an ON-pathway disorder (Kim *et al*., 2022) may result in the improvement in reading performance with RP.

There was a large variability within the groups at an individual level with some children showing an improvement in reading performance whilst others did not when RP text was used. There was no direct physiological explanation for these findings. For example, a 12-year-old female with cone dystrophy, had a virtually unrecordable 30Hz flicker amplitude of 1.0µV with distance VA of 1.00 logMAR was excluded from analysis due to her slow reading speed with NP print, which made it not possible to calculate a CPS. However, when polarity was reversed, the minimum font size she could read reduced from 46-point font with NP, to 23-point font with RP and her MRS increased nearly 10-fold from 4.7 WPM with NP to 40.0 WPM with RP print. A recent case report of a child with a cone-dystrophy also demonstrated the impact of RP text on reading performance based on measures of reading speed and print size requirements supporting the potential of RP print to assist some students with a VI to improve their reading performance. See **Chapter 5** and Loh *et al*., (2022). In contrast a 14-year-old male with ONH and a VA of 0.40 logMAR demonstrated poorer reading performance with RP reading material. His minimum acuity increased from 12-point font with NP, to 15-point font with RP. CPS size increased from 14-point to 18-point font and MRS reduced from 84 to 58 WPM. These clinical cases further demonstrate the need for an individual assessment to determine if changing print polarity will benefit a student or not in the classroom.

4.5.4 Conclusions

Childhood VI is complex, and different pathologies demonstrate different visual behaviours. This study has shown that RP print has a role to play in the support of some students with a VI, particularly students with retinal dystrophies. However, retinal dystrophies are a heterogeneous collection of disorders, with a wide range of defects at the molecular and cellular level affecting primarily rod or cone pathways or the macular region (Verbakel, *et al*., 2018). It may not be possible to fully understand the process of why some students prefer RP. Individual assessments, however, may provide enhanced support for students with VIs and allow for tailored requirements to their specific needs. This would determine the most appropriate, and comfortable, tools to access educational materials throughout education.

Some students with retinal dystrophies may benefit from using RP on electronic and printed materials without the need for larger font sizes. Students affected by glare, such as albinism and nystagmus, may also benefit from the use of RP text while using electronic font, but may require enlargement of font size for sustained reading. Further work is required to investigate a comprehensive range of functional requirements, on an individual basis, to enable adequate support of a child with a VI through their education.

4.5.5 Relevance to Research Questions

This part of the thesis demonstrated that there can be significant improvements in the reading performance for some students with a VI using RP text. These improvements appear to be dependent on the underlying pathology. However, there are significant limitations to this analysis and a larger investigation is warranted to determine the mechanisms of why certain pathologies i.e., retinal dystrophies benefit from RP. In this analysis, due to unavailability of medical records or insufficient detail on pathology, retinal dystrophies were grouped together. Also due to restrictions in recruitment and testing during the Coronavirus Disease 2019 (COVID19) pandemic impacted the sample size obtained based on pathological groups. Furthermore, given the large heterogeneity in the cause and effects of the group containing ‘retinal dystrophies’, it was difficult to form concrete conclusions on the impact that RP has on the subsets contained within this group and whether differences were more prevalent in rod or cone-based dystrophies for example.

It has been reported that individuals that suffer from glare benefit from reversing the polarity on the screen which reduces screen luminance (Legge *et al*., 1985). This study also demonstrated that students with albinism benefitted from RP, presumably due to similar issues with glare and photophobia. However, they also required an increase in CPS to read at optimum efficiency with RP text. This is consistent with previous studies in individuals with normal vision that require an increase in font size when using RP (Bruchner *et al*., 2009).

This part of the thesis revealed the need for further studies to determine the factors that best identify an individual who will improve reading performance with RP text. This would help identify those most likely to benefit and could support a child with a VI in the classroom and at home with their reding.

4.6 Feature based visual search in children with a visual impairment

Visual search is the ability to locate and identify and locate a target efficiently and accurately (Wolfe, 2021). Within the classroom, search ability plays a vital role in several aspects. Students may need to locate and attend to specific items, such as locating a particular word in text, information in graphs or tables, or following instructions presented visually. During reading and comprehension, visual search capability is essential to accurately locate and track words, sentences, and paragraphs on a page. Effective visual search skills enable students to identify relevant information, make connections between different parts of text and extract meaning from written material.

Difficulty with visual search, particularly as visual information becomes more complex or cluttered, can impact a student's learning experience. A reduced visual search ability may lead to difficulty maintaining focus on school-based tasks, reduce comprehension of text, slower and less accurate task completion, or difficulty following instructions.

The following section of this thesis contains published work based on feature-based search in children with a vision impairment.

Constable PA, **Loh L**, Prem-Senthil M, Marmolejo-Ramos F. Visual search and childhood vision impairment: A GAMLSS-oriented multiverse analysis approach. *Atten Percept Psychophys*, 2023;85(4):968-977. doi:10.3758/s13414-023-02670-z

Attention, Perception, & Psychophysics
https://doi.org/10.3758/s13414-023-02670-z

SHORT REPORT

Visual search and childhood vision impairment: A GAMLSS-oriented multiverse analysis approach

Paul A. Constable[1] · Lynne Loh[1] · Mallika Prem-Senthil[1] · Fernando Marmolejo-Ramos[2]

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4.6.1 Introduction

The aim of this section of the thesis was to investigate the impact of childhood VI on a feature based visual search task. It has previously been shown that small amounts of blur or visual field defects can impact attention and performance on non-verbal visual tasks such as visual search (Bertone *et al*., 2007; Cornelissen, 2005). Oculomotor control and VA are key elements that affect attention and the ability to perform visual search tasks. Individuals with conditions that impact VA and or oculomotor control such as Alzheimer's or Parkinson's disease demonstrate poor performance in visual search (Buchmann *et al*., 2015; Pereira *et al*., 2020).

Several studies have explored search performance in both adults and children with acquired or inherited VI affecting acuity, central and peripheral vision. The systematic review of Senger *et al*., (2017) reported the overall worsening of visual search with VI. Conditions affecting visual fields can restrict the ability to search due to the presence of scotomas, and conditions affecting the central vision (such as Stargardt's) were particularly related to a decrease in search performance. The review also found that conditions impacting contrast sensitivity and brightness discrimination, such as retinal dystrophies and albinism, interfered with the contours and shape of visual search targets, impacting search performance (Senger *et al*., 2017).

VI based on VA or visual field may not fully characterise the impact on visual performance related to activities involving visual search such as reading and following classroom activities (Pai *et al*., 2011). The impact of a VI in adults with daily tasks of living is significantly affected by difficulty in visual search that impacts mobility and tasks such as reading, walking safely outdoors, preparing meals, or engaging in physical exercise (Szlyk, 2001). To further explore the additional time taken with visual search tasks this thesis adopted a standard feature search paradigm that has been used previously with children and adolescents (Constable *et al*., 2010; O'Riordan 2004).

Tadin *et al*., (2012) reported a four second delay in search time when subjects with a VI were asked to locate an object within a visual scene such as a stapler within an office space. This 'extra time' or lag in locating an object may be confounded by the presence of nystagmus in children with a VI as the number or complexity of the distractors increases (Huurneman *et al*., 2014). The impact of nystagmus on refixation and ocular-motor control are the main reasons for poorer search performance based on search times, reported in a subset of individuals with a VI (Fu *et al.*, 2011; Huurneman *et al.*, 2014). Some studies have identified methods to improve search performance by individuals with a VI by enhancement of natural scenes by modification of spatial frequency content on screens (Luo *et al.*, 2012; Tang *et al.*, 2004) but this may be impractical in a real-world situation.

4.6.2 Methods

Participants

A total of 39 students with a VI were recruited from the South Australian School and Services for Vision Impaired, of which 32 (82%) had nystagmus. The mean ± SEM binocular visual acuity of the VI group was logMAR 0.63 ± 0.05 with range of 0.21 to 1.46 (~6/9.5-6/180) measured using the FrACT (Bach, 1996) as previously described in **Chapter 3.2**. Comparison control children (*n*=33) were recruited from local schools and friends and family who had normal to near normal (better than 0.1logMAR) corrected acuities and no oculomotor imbalances. There were no significant differences between groups for age: VI 11.6 ± 0.5 and control 13.0 ± 0.5 years (Mann-Whitney-U *p*=.052) and gender (sex) (VI male *n*=22 (56%) and control *n*=19 (61%) (chi-squared X^2 (1) =.03 *p*=.87). The VI group consisted of students with a diagnosis of albinism (*n*=12) or inherited retinal disease (*n*=12), visual pathway (optic nerve hypoplasia/atrophy *n*=6), congenital nystagmus (*n*=4), congenital cataract (*n*=2), and *n*=1 each of retinopathy of prematurity, myopia, anterior uveitis/cataract.

Visual Search

Methods for this study have been described in **Chapter 3.3.3** For this feature search task, the search target ellipse and distractor circles were presented on the display of a MacBook Air-11.6-inch display (1366 x 768 pixels at 75Hz) with mean luminance of 65 cd/m^2. The participants were seated comfortably at a viewing distance of 40cm. Habitual correction was worn if required and room illumination was dim.

Two different stimuli were used in this study- a white circle (distractor) and a white ellipse (target) illustrated in **Figure 4.19**. The circle had dimensions of 0.8cm x 0.8cm projecting visual angle of 1.15˚ whilst the ellipses had dimensions of 0.7cm x 1.0cm projecting visual angle of 1.00˚ and 1.43˚, respectively. These stimuli were further refined via anti-aliasing process through a Gaussian blur kernel (σ of 2-pixels) which reduced image noise and smoothed the border of the circle and ellipse.

The stimuli were equally spread on a 12x12 grid to allow equal number of stimuli on each side from the point of fixation. Three set sizes were used with either target present or absent consisting of 4, 16 and 24 items displayed randomly within the grid and presented randomly for each trial. At the start of each trial the subject was instructed to press the key ‘P’ if the ellipse was present or the key ‘A’ if the ellipse was absent. A total of 80 presentations were performed in each trial. The subject was instructed to do the task as quickly and as accurately as possible. See **Figure 4.19** for sample display of the feature task with target absent and target present for set size 24.

Figure 4.19: Display for visual search task

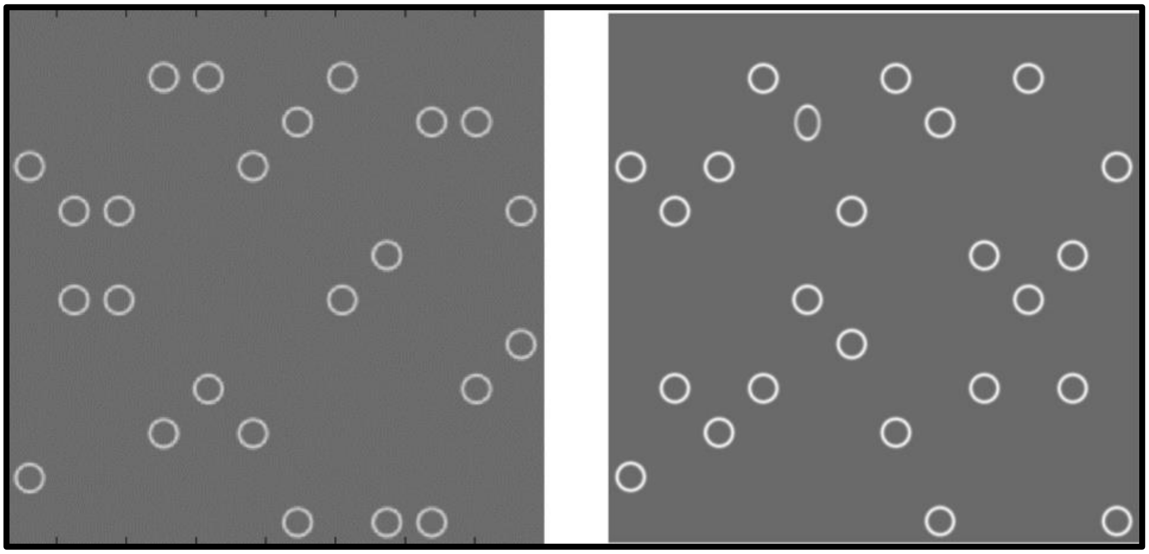

Figure 4.19. Display presentations for the feature search task with set size 24. Left figure shows the absent condition, and the right figure shows the target present condition in which an ellipse is present withing the circular distractors. Figure from Constable, Loh *et al*., (2023).

Data and Statistics

Methods for mean RT and accuracy for the set sizes and target present and absent conditions are described in detail in **Section 3.3.3**. Statistical Modelling was performed by Dr Fernando Marmolejo-Ramos, Centre for Change and Complexity in Learning, The University of South Australia, Adelaide, South Australia, Australia. Interactions and main effects were analysed using a statistical method blending GAMLSS (generalised additive models for location, scale, and shape) and distributional regression trees.

Data extraction was performed as previously described in **Chapter 3.3.3.**

4.6.3 Results

Distributional regression trees

Distributional regressions trees are regression models encompassing elements of decision trees (decisions made on features) and statistical distributions (likelihood of outcome). For a full explanation of the statistical modelling, see Constable, Loh *et al.*, (2023). The upper branches of the tree are more important than the lower branches because they have differences in location, scale, and shape. The top branch representing the starting point for decision making, which involves comparing the distributions of set size 4, and then set sizes 16 and 24 in both the reaction time regression tree and the accuracy regression tree (**Figures 4.20 and 4.21**).

Reaction times

Commencing at the top of the tree with set sizes, there was a significantly slower reaction time demonstrated between set sizes 4 and set sizes 16 and 24 (p<.001).

Branch Set size 4: reaction time was slower for the vision impaired group at set size 4 (p<.001) compared with the control group. Within the control group, reaction time was dependant on whether the target was present or absent, with the target absent group being significantly slower (p<.05).

Branch Set sizes 16 and 24: the control group demonstrated significantly faster search times than the vision impaired group when the target was either absent or present for set sizes 16 and 24 (p<.001).

Within the VI group, when the target was absent, females demonstrated a significantly longer search time than males (p<.05). Conversely, when the target was present, within the control group, males demonstrated a slower search time than females (p<.05).

Figure 4.20: Distributional regression tree for reaction time

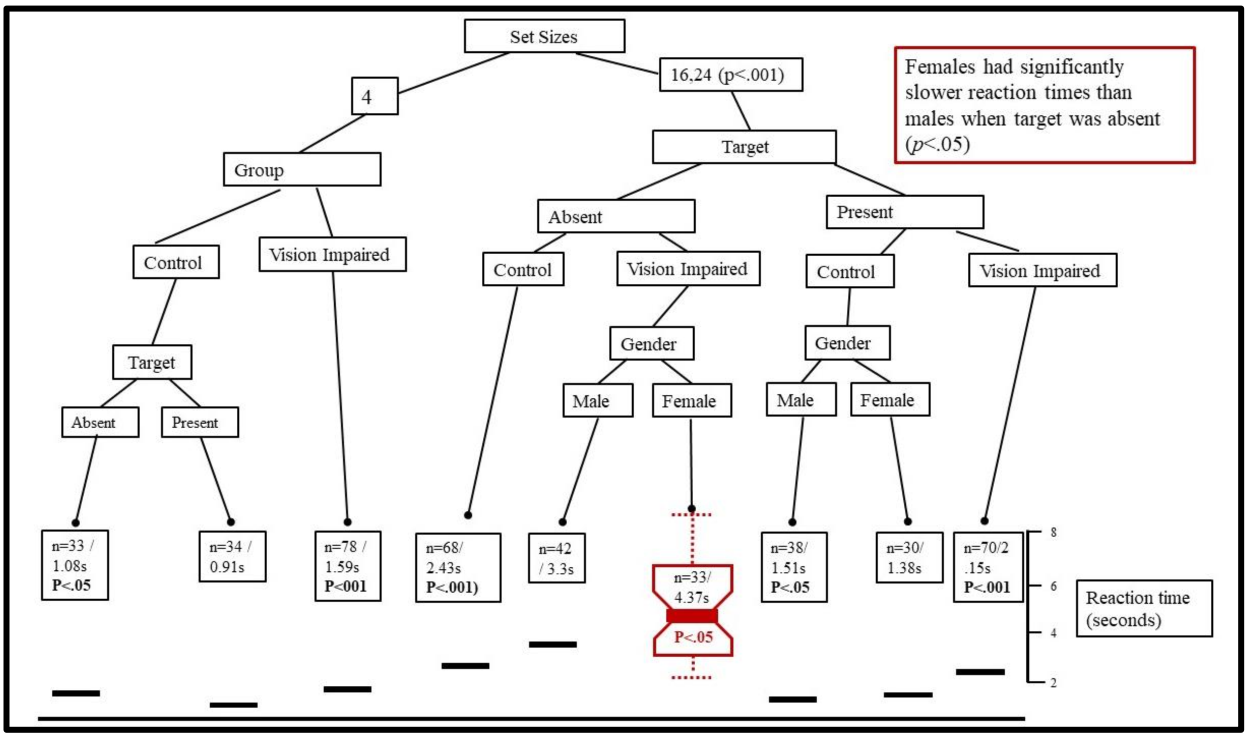

Figure 4.20. Distributional regression tree for reaction time. Students with VI demonstrating significantly slower reaction time across all set sizes with reaction times slower with increasing set sizes (p<.001). Female students also demonstrated a significantly longer search time than males when the target was absent (p=.05) Figure adapted from Constable, Loh *et al*., (2023).

Accuracy

Commencing at the top of the tree with set sizes, there was a significantly reduced accuracy demonstrated between set sizes 4 and set sizes 16 and 24 (*p*=.002), demonstrating that accuracy decreased as set sizes increased.

Branch Set sizes 16 and 24: Accuracy was significantly higher when the target was absent than present in set sizes 16 and 24 (*p*=.005). Within the target present branch, age was the only significant factor with students less than 14 years demonstrating significantly reduced accuracy (*p*=.03).

Figure 4.21: Distributional regression tree for accuracy

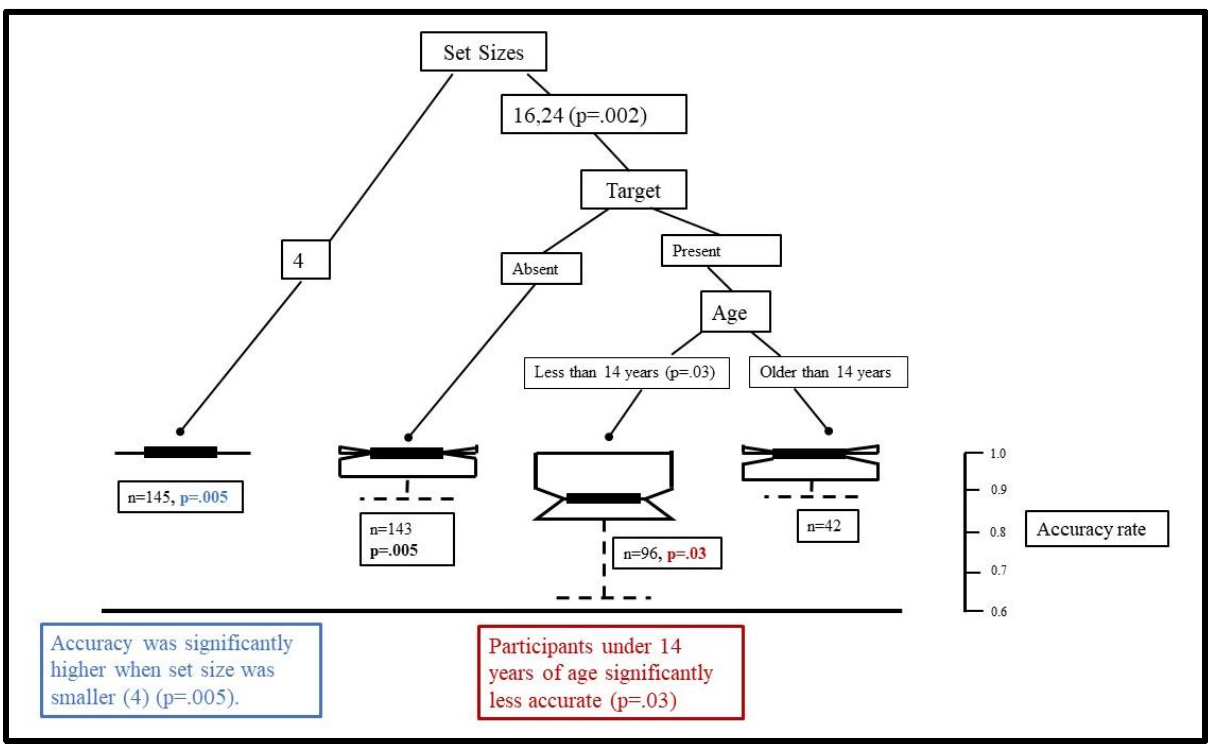

Figure 4.21. Distributional regression tree showing the relationship between set size and accuracy. With significantly higher accuracy with smaller set sizes (*p*=.005) and students under 14 years old significantly less accurate (*p*=.03). Figure adapted from Constable, Loh *et al.*, (2023).

4.6.4 Discussion

In both regression trees the largest factor impacting visual search performance was the number of set sizes, meaning that visual performance depended on the number of distractors. This is consistent with previous research as the number of distractors increase, the speed and accuracy of visual search declines (Huurneman *et al*., 2016b). In a classroom environment, this information is important for students who are required to scan complex information for relevant details, such as comprehension, internet searches or detecting specific information in graphs or tables.

Reaction times

Across all set sizes students with a VI demonstrated reduced reaction times regardless of whether the target was absent or present when compared with the control (normal vision) group. RTs were significantly longer when set sizes increased and there were therefore more distractors ($p>.001$). There was also a positive correlation between mean RT and VA ($p<.001$), with students with the lower acuity also having slower search times. Interestingly, within the VI group, when the target was absent, females demonstrated a significantly longer search time than males ($p<.05$), which is thought to be due to a more cautious approach taken to look for information.

The VI group consisted of children with a diagnosis of: albinism or inherited retinal disease n=12, visual pathway (optic nerve hypoplasia/atrophy) n=6, infantile idiopathic nystagmus n=4, congenital cataract n=2, and n=1 each of ROP, myopia, anterior uveitis/cataract. Nystagmus was present in 83% of the students with a VI, which is known to affect visual search ability. Huurneman *et al*., (2014) investigated visual search in children with normal vision and children with a VI of which 26 had nystagmus secondary to their VI, and eleven had a VI with no nystagmus. The group performed several search tasks based on a feature search in a row or matrix, and a conjunctive search where features of the target are shared by the distractor. The group also recorded eye-movements during the study and concluded that children with nystagmus performed worse than those without, and that search times were reduced as task complexity increased from row to matrix to conjunctive search. The authors concluded that differences in search ability was related to a greater number of fixations and oculomotor control, which was more evident in the group with nystagmus. Further support could be provided for children with nystagmus and VI as suggested by Huurneman *et al*., (2014) by increasing line spacing and or a comprehensive assessment of search ability in a student with a VI to identify strategies to improve search performance (Senger *et al*., 2017).

This section of the thesis in a slightly larger sample also supports the need to evaluate visual search and develop strategies that may help a child with a VI improve their ability to read and engage with classroom activities. This may be simply increasing time allowances to perform visual search tasks or adapting classroom materials such as increasing line spacing to reduce the spacing of distractors or by increasing spacing between letters in words and allowing extra time for children to locate a target during a classroom task such as a comprehension exercise.

Accuracy

Accuracy was similarly affected primarily by set sizes, with accuracy significantly higher when set size was smaller in both control and VI groups (p=.005). With set sizes 16 and 24 accuracy was significantly higher when the target was absent (*p*=.005), suggesting that more errors were made when the target is present in larger set sizes.

When the target was present age became a significant factor and participants under 14 years were significantly less accurate when the target was present (*p*=.03), which could possibly be related to visual search development and age.

Despite accuracy being affected by set size, presence of target and age, VI was not a significant factor relating to accuracy.

4.6.5 Relevance to Research Questions

Visual search plays an important part in a student's visual performance within a class environment. The results from this section of the thesis have revealed that students with a VI have slower search times, and more importantly the search time is increased with increasing number of distractors. This will impact students as they progress through schooling, particularly as they are undertaking independent research and are required to find relevant information in large amounts of text, search the internet for information, or analyse complex graphs, charts, or tables.

One of the more interesting outcomes to this study was the longer search time shown in females when the target is absent. This observation had been anecdotally noted by teachers during the assessment process, and observations on classroom learning by support teachers. It has previously been perceived that males and females search for information differently within the class environment. Males tend to perform a search and “move on” if the detail is not found. Female students, conversely, have been observed to take a more cautious approach to locating detail, and will rescan information, sometimes several times, to ensure that detail has not been missed. This more cautious approached employed by female students is thought to be the reason for the longer reaction time when the target is absent and is valuable information for teachers. If a female student is asked to perform a task that requires a search for information, she may require a significantly longer time to perform the task.

Additionally, this section of the thesis has shown that despite the reduced search times for students with a VI, the accuracy is the same with no statistically significant differences in accuracy across all factors. Suggesting that VI has no effect on accuracy of this feature-based search task, just the time taken to perform it.

4.7 Crowding Intensity

Crowding Intensity refers to the degree of visual crowding. Crowding is a visual perception phenomenon where the presence of nearby objects or elements interferes with the accurate recognition or identification of a target object based on the limits of cortical processing in V1 (Pelli, 2008).

When a target object, such as a letter or shape, is surrounded by other distracting elements or ‘flankers’, the cortical spacing and processing limits reduce the ability to discriminate the object of interest such as a letter or word (Pelli and Tillman, 2008). Crowding Intensity is a measure of how the presence of nearby distractors interfere with the perception of the target. This term is defined as the difference in logMAR acuities between crowded and uncrowded tasks (Huurneman *et al*., 2012; 2016a: van Genderen *et al*., 2012).

Crowding Intensity may impact a student within a classroom, particularly reading and writing. It can result in slower reading speeds and reduced comprehension (He and Legge, 2017), and a large Crowding Intensity interferes with word and letter recognition (Huurneman *et al*., 2014). It can also result in difficulty with visual search and locating specific information within text, tables, or graphs. Students that are impacted by Crowding Intensity may struggle to process and perceive crowded visual information (van Genderen *et al*., 2012), which can lead to visual fatigue (Schakel *et al*., 2019).

4.7.1 Methods

FrACT was used to measure both uncrowded best corrected binocular VA in participants as shown in **Figure 4.22**. Crowding Intensity was calculated as the difference in VA between uncrowded and crowded binocular VA. The distance 'gapsize' to the flankers around the target Landolt C was 2 x the stroke width, where the stroke width is 1/5th the size of the Landolt C.

Figure 4.22: Uncrowded and Crowded Landolt C

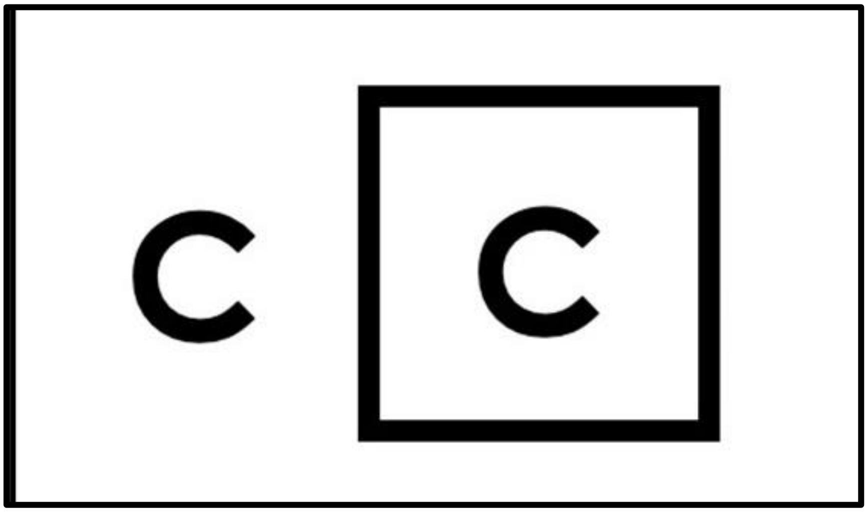

Figure 4.22. Uncrowded (left) and crowded (right) Landolt C target. The Crowding Intensity is the difference in logMAR acuity between the uncrowded Landolt C and a crowded Landolt C, which is surrounded by a crowding box at a spacing of twice the limb (gap) of the Landolt C.

4.7.2 Results

Thirty-five participants with a VI had measures of both crowded and uncrowded binocular VA. Their uncrowded VA was 0.78 ± 0.41 logMAR, and their crowded VA was 0.77 ± 0.39 logMAR. The Crowding Intensity was 0.05 ± 0.09 logMAR, with a range from -0.11 to 0.29 logMAR. The distribution of Crowding Intensity for the VI group is shown in **Figure 4.23**.

Figure 4.23: Distribution of Crowding Intensity

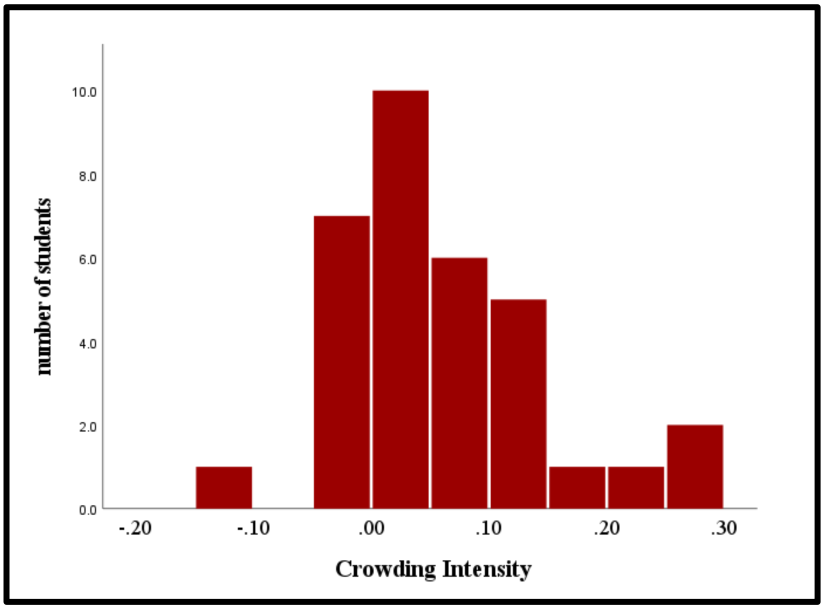

Figure 4.23. Histogram of the distribution of Crowding Intensity (difference in logMAR acuity between uncrowded and crowded Landolt C) within the vision impairment study group which ranged from -0.11 to 0.29 logMAR.

Each letter on a logMAR chart equates to 0.02 log units, one line on a logMAR chart with 5 letters per row is 0.10 logMAR units. These results show that Crowding Intensity measures vary from a difference of a one-line improvement with crowded acuity (single subject) to almost a three-line decrease in VA with a crowded target. A large percentage of the students (69.7%) had less than a one-line change in VA with a crowded target, 21.2% had more than a one-line change in VA, and 9.1% had more than a two-line change in VA as illustrated in **Figure 4.24**. The VI participants with the greatest Crowding Intensity are more likely to demonstrate difficulties within the classroom in terms of reading speed and letter identification (Dekker *et al.*, 2012; He and Legge, 2017; Huurneman *et al.*, 2012).

The variation in these findings support the necessity to measure crowing intensity in students with a VI. Determining which students have a higher Crowding Intensity and adjusting their work format accordingly can impact the ability to efficiently access classroom tasks (He and Legge, 2017).

Figure 4.24: Crowding Intensity levels

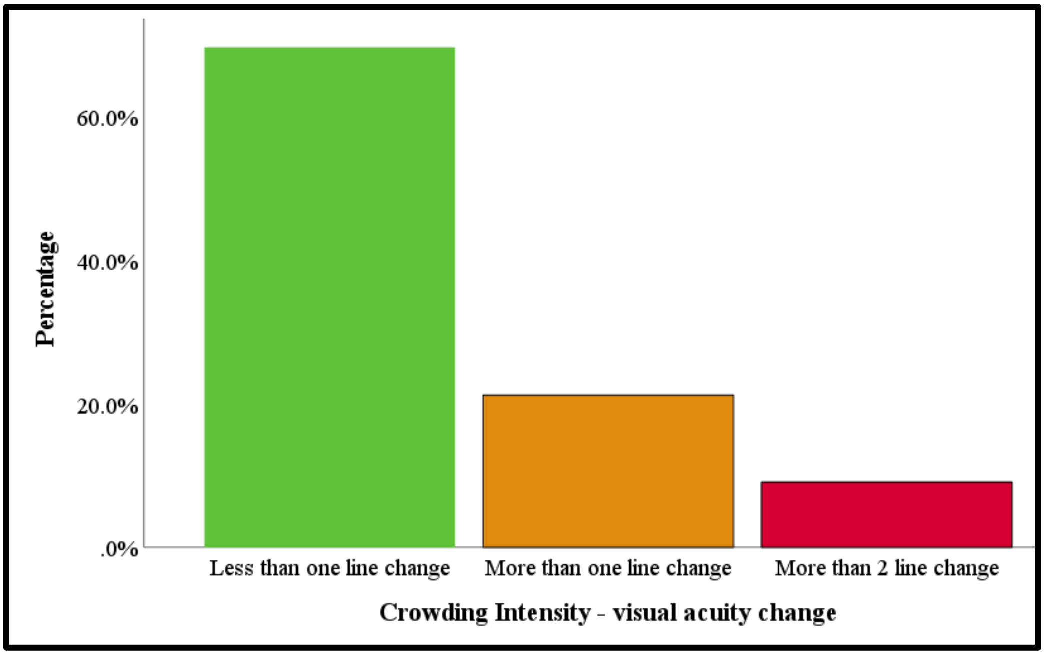

Figure 4.24. The percentage of vision impairment students that demonstrated less than a one-line change (green), more than a one-line change (orange), and more than a two-lines (red) of change in logMAR visual acuity between the uncrowded and crowded Landolt C condition.

4.7.3 Crowding Intensity and Visual Acuity

Methods

Crowding Intensity was also correlated with Visual Acuity, to determine if there was a relationship between the degree of Crowding Intensity and VA. Both uncrowded and crowded binocular VA were compared with Crowding Intensity.

Results

There were no significant relationships between crowded binocular VA and Crowding Intensity (p=.19, r^2=0.06), or uncrowded binocular VA and Crowding Intensity (p=.96, r^2<0.01) as shown in **Figure 4.25**. There were also no significant relationships between crowding intensity and pathology or age.

Figure 4.25: Visual Acuity and Crowding Intensity

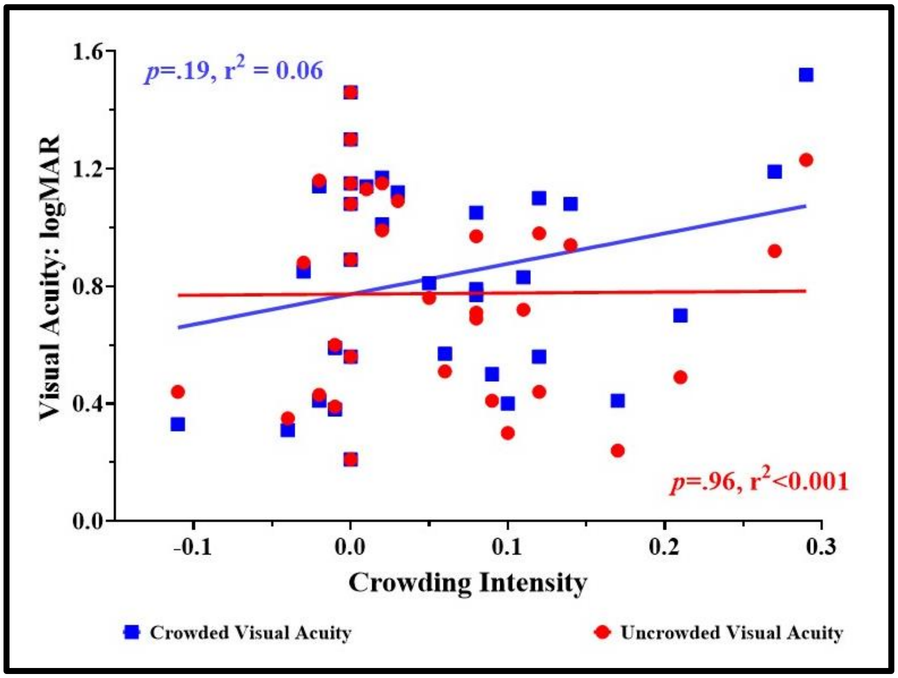

Figure 4.25. Correlation of Crowding Intensity and crowded and uncrowded visual acuity. No significant correlation was found between Crowding Intensity and binocular crowded visual acuity (p=.19, r^2=0.06) or uncrowded visual acuity (p=.96, r^2<0.001).

These results demonstrated that there was no relationship between the degree of Crowding Intensity and VA. Despite a large Crowding Intensity impacting a student's ability to work effectively within the classroom environment (Dekker *et al.,* 2012; He and Legge, 2017 Huurneman *et al.*, 2012), these findings support the contention that the degree of Crowding Intensity cannot be reliably estimated from VA measures.

4.8 Reading Reserve

Reading Reserve (RR) is the ratio of the smallest print an individual can see (reading acuity) to the optimum print size a student can read at maximum speed (CPS). The RR for normally sighted individuals is approximately 3-4 times (Lueck *et al*., 2003). For example, an individual with 0.00 logMAR vision (6/6) would be able to read approximately font size 4-point at 40 cm. However, for comfortable reading throughout the day, most individuals prefer to use a RR of 3 times, which would equate to font size 12 at 40 cm (i.e., 3x4) as shown in **Figure 4.26**.

Figure 4.26: Reading Reserve

Ratio of the smallest print an individual can see (resolution acuity/ reading acuity) to the optimum print size for reading (critical print size)

Ratio of the smallest print an individual can see (resolution acuity/ reading acuity) to the optimum print size for reading (critical print size)

Figure 4.26. The above figure is a representation of a reading chart, with the top line in size 4-point font demonstrating the minimum font size that can be seen by an individual with 0.00 logMAR (6/6) visual acuity at 40cm, and the bottom line in size 12-point font at 3 x reading reserve.

4.8.1 Methods

RR was calculated using data obtained from the reading assessments on the MNREAD for all students, using NP and RP text. The RR was calculated as a ratio of minimum reading acuity (smallest font size read) with critical print size (smallest font size read at maximum reading speed). The RR was also compared with binocular distance VA and reading acuity.

4.8.2 Results

Reading Reserve

The RR was 1.29 ± 0.33 (range 0.96 to 2.69) with NP print (*n*=53), and 1.31 ± 0.46 (range 0.83 to 3.85) with RP print (*n*=49).

For both NP and RP text, 96% of students with a VI were working at near with a RR < 2, which is less than the value of 3 that normally sighted individuals would use to read text comfortably. **Figure 4.27** shows the distribution of the RR for NP and **Figure 4.28** shows the distribution of RR for RP text.

Figure 4.27: Distribution of reading reserve for normal polarity text

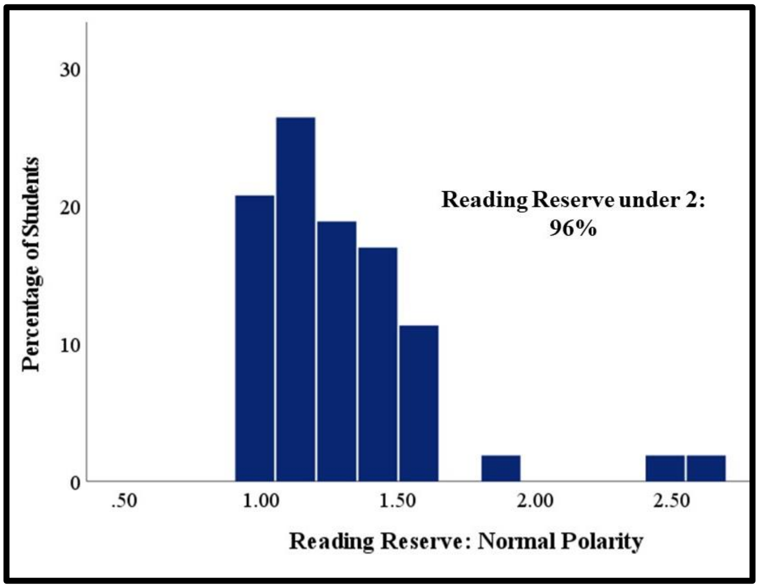

Figure 4.27. Distribution of Reading Reserve (RR) for normal polarity text with 96% of students with a VI reading at a RR <2.

Figure 4.28: Distribution of reading reserve for reverse polarity text

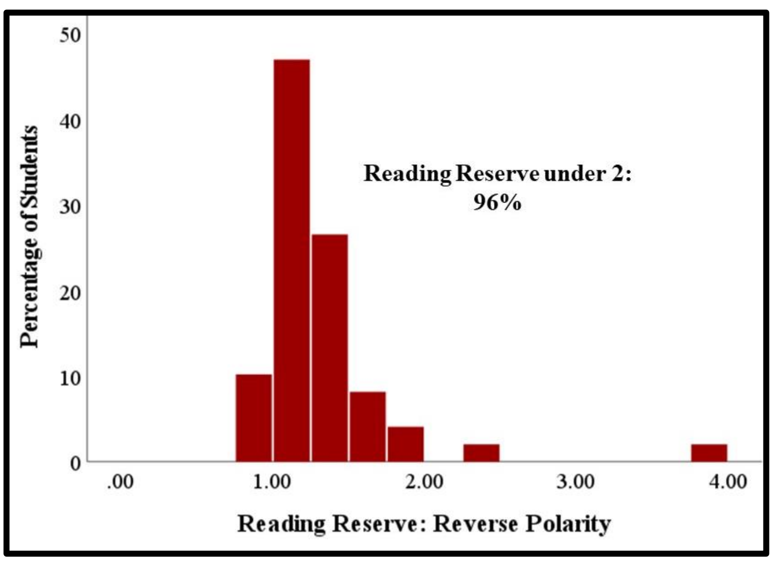

Figure 4.28. Distribution of Reading Reserve (RR) for reverse polarity text with 96% of students with a VI reading at a RR <2.

Reading reserve and distance visual acuity

Figure 4.29 shows the significant negative correlations between the RR and distance VA for both NP (*p*=.004) and RP text (*p*=0.03) with poorer distance VA associated with a lower RR.

Figure 4.29: Reading Reserve and distance visual acuity

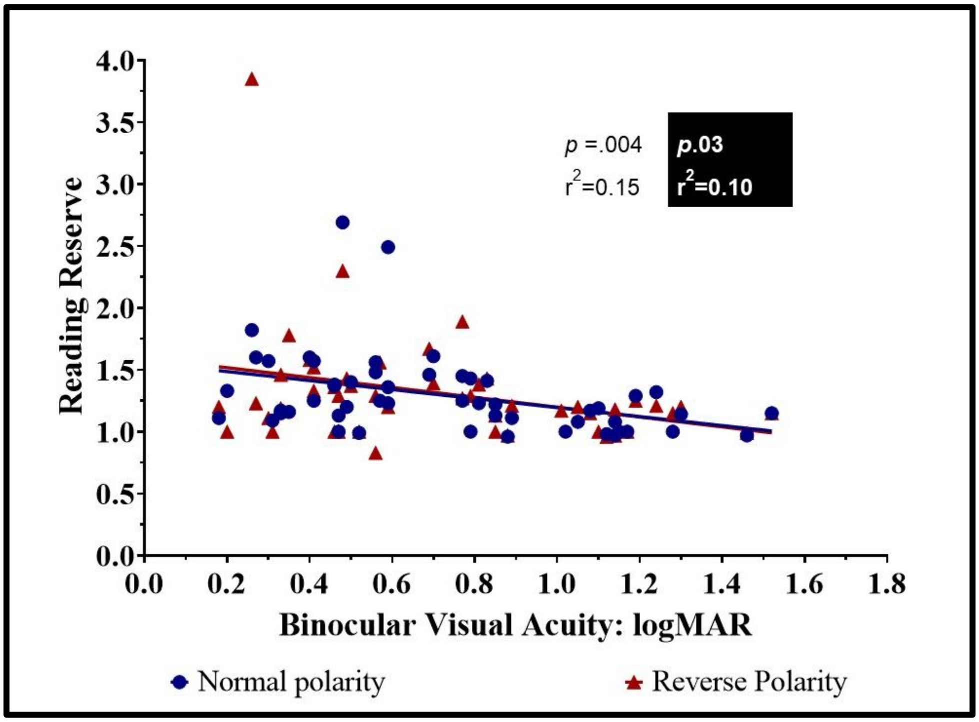

Figure 4.29. The RR and binocular VA had a significant negative correlation for both NP (*p*=.004) and RP print (*p*=.03) in the vision impairment group.

Reading reserve and reading acuity

There was also significant negative correlation between the RR and near reading acuity for both NP (*p*<0.001) and RP print (*p*<0.001) with poorer reading acuity associated with a reduced RR as shown in **Figure 4.30**.

Figure 4.30: Reading Reserve and reading acuity

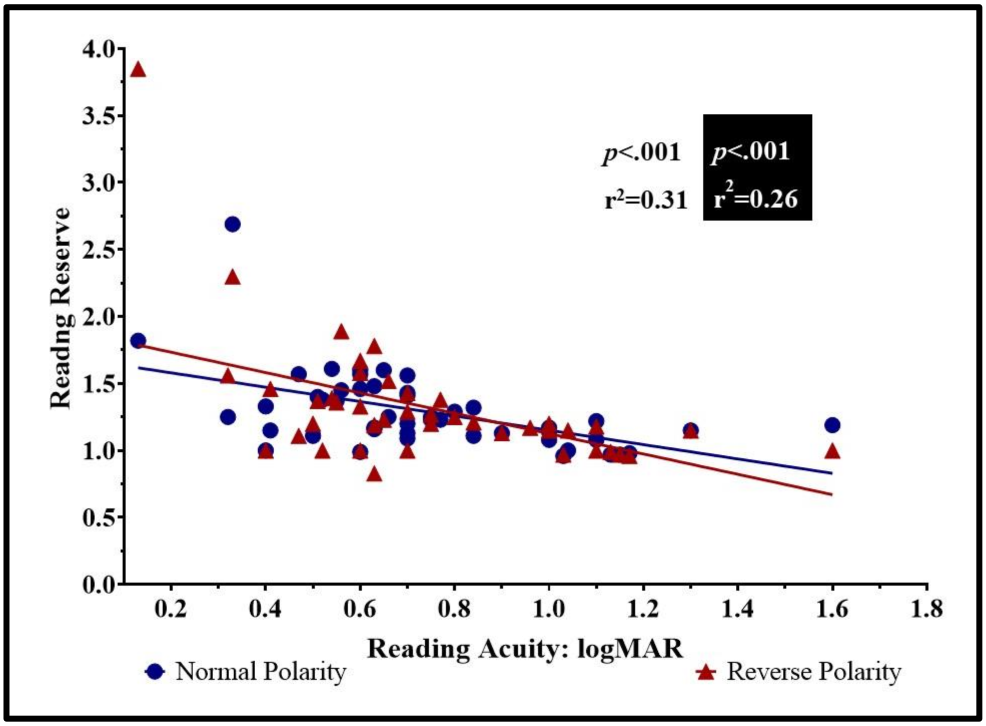

Figure 4.30. Reading Reserve and near reading acuity were negatively correlated with Normal Polarity (p<.001) and Reverse Polarity text (p<.001).

4.8.3 Relevance to Research Questions

Understanding the impact of a lower RR is essential for educators to enable a student's ability to maintain engagement with the curriculum throughout the day at school. These results indicate that students with a VI are using a lower RR than typically recommended for students with a VI (Lueck *et al*., 2003). The students with lower VA or reading acuity, RR is reduced so that these students are reading nearer to their absolute reading acuity limit which is likely to contribute to visual fatigue. This may affect concentration and maintaining focus on tasks, and as visual fatigue increases this may manifest as a slower reading speed, decreased comprehension, headaches, or avoidance of tasks, and may even manifest as behavioural changes (Schakel *et al*., 2017; 2019).

4.9 Reading Reserve and Crowding Intensity

The investigation of RR with Crowding Intensity was designed to determine if the students with a larger Crowding Intensity utilised a larger RR, to overcome the effects of crowded letters by increasing word size and letter spacing. This was done by correlating the RR and Crowding Intensity for NP and RP text.

4.9.1 Results

There was an overall positive trend for the RR to increase with increasing levels of Crowding Intensity, however the correlation just failed to reach significance (r^2=.12, p=.06) as shown in **Figure 4.31**.

Figure 4.31: Crowding Intensity and reading reserve

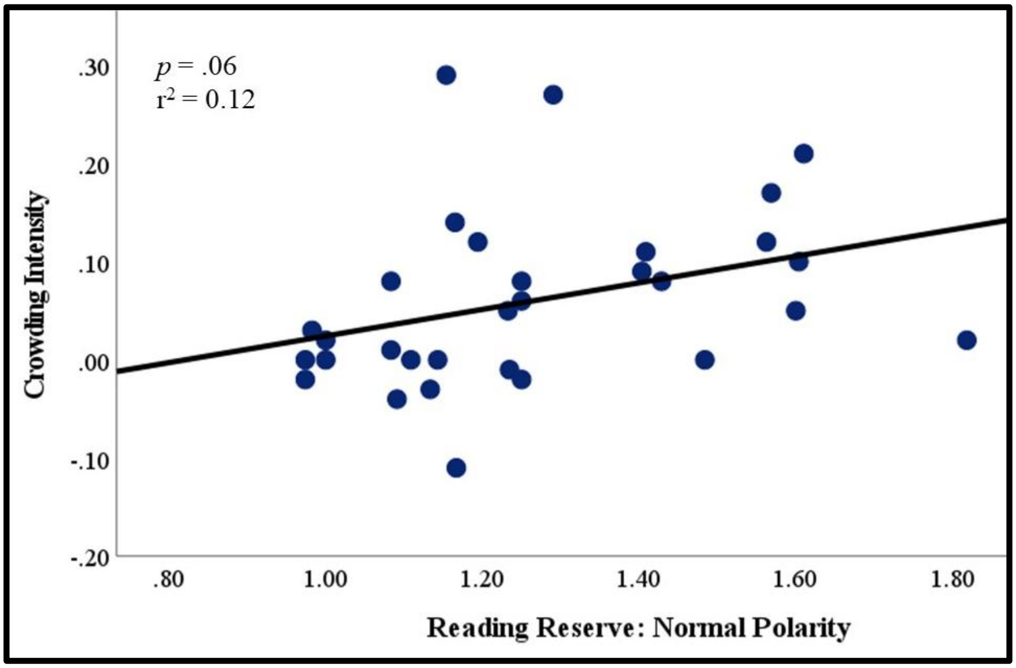

Figure 4.31. Correlation of Crowding Intensity and reading reserve with normal polarity print. There was a trend for reading reserve to increase with an increase in Crowding Intensity, however this did not reach significance.

There was a similar trend for the RR to increase with increasing Crowding Intensity using RP text, but this relationship also failed to reach significance (r^2=.08, p=.13) as shown in **Figure 4.32**.

Figure 4.32: Crowding Intensity and reading reserve

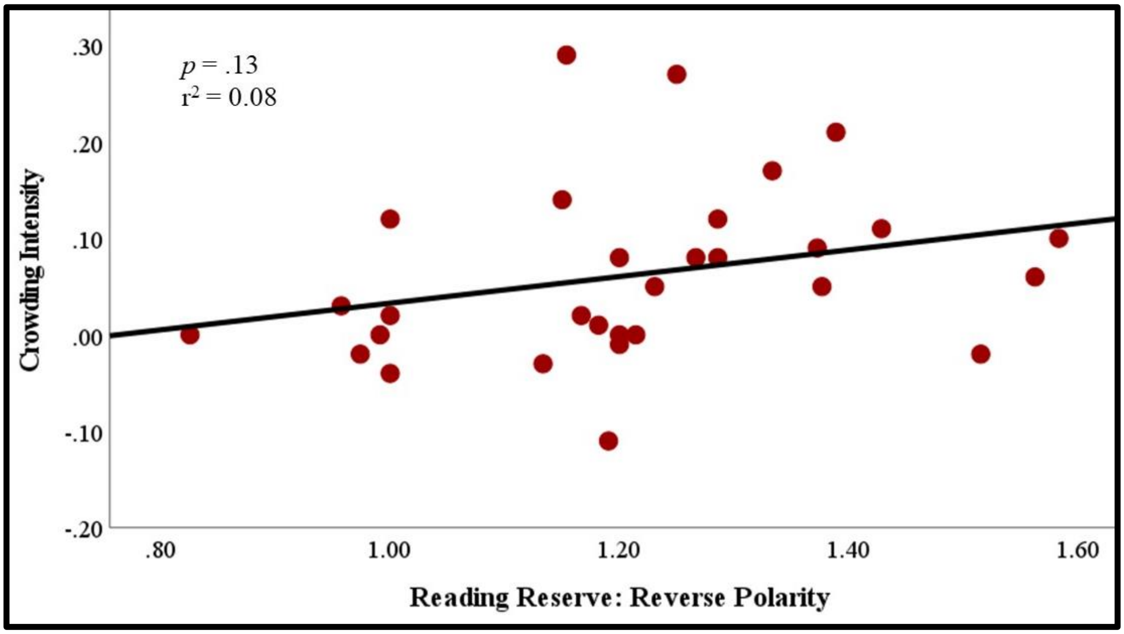

Figure 4.32. Correlation of Crowding Intensity and reading reserve with reverse polarity print. There was a similar trend for reading reserve to increase with an increase in Crowding Intensity, this again did not reach significance.

4.8.2 Discussion

As expected, the degree of Crowding Intensity is associated with a need for larger font size to mitigate against the effects of crowding. The use of a larger font would result in less words on a page and greater spacing between letters resulting in better reading performance. However, despite the observed positive trends with RR and Crowding Intensity the relationships failed to reach significance (p>.06) with NP or RP screen-based text. Therefore, it is not possible to predict RR from Crowding Intensity but for those with higher Crowding Intensity a larger font size may be required to improve their reading performance.

4.10 Vision Processing

4.10.1 Test of Test of Visual Analysis Skills

Of the *n*=53 participants that completed the TVAS, *n*=29 (54.7%) passed the test by copying all 18 grid patterns correctly. Of the *n*=24 that were unable to correctly complete the test, results varied for the grid patterns they were able to complete accurately, as detailed in **Table 4.9**.

Table 4.9: Number of students and grid pattern completed

Plate number	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**16**	**18**
n	7	4	4	1	1	2	4	1	29

Table 4.9. Upper row shows the last grid pattern completed correctly of the Test of Visual Analysis Skills, a visual motor integration task with the larger grid pattern number requiring higher levels of visual-motor integration. Lower row shows the number (*n*) of students reaching each plate number successfully, with 29 participants correctly completing the final plate 18.

Some examples of incomplete TVAS plates are shown in **Figure 4.33** that were incorrectly attempted by participants. There was no correlation between VA and the TVAS scores (r^2=0.002, *p*=.74) indicating that VA alone was not a good predictor of visual motor integration in this cohort.

Figure 4.33: Examples of incorrectly completed grids

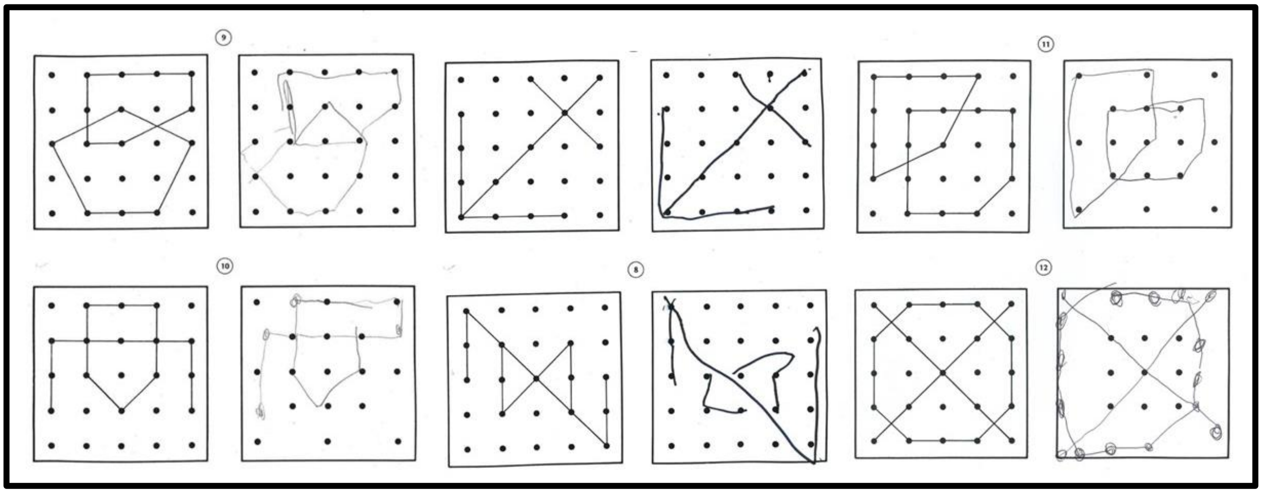

Figure 4.33. Examples of incorrectly copied grid patterns using the Test of Visual Analysis Skills. The participant was asked to copy the figure on the left using the grid of points as a guide.

A correlation of TVAS scores and chronological age (years) demonstrated a significant positive correlation (r^2=0.32, p<.001), between the TVAS plate completed and age. This was expected as visual motor integration increases with development (Braddick and Atkinson, 2007). However, the scatter plot revealed that there were two subsets of students whose TVAS scores were either normal (completed plate 18) or were reduced and did not rise above a score of 8. These differences in performance highlight the need to evaluate the TVAS for each student with a VI to evaluate their performance level as shown in **Figure 4.34**. No relationships were found between TVAS score and pathology, indicating that reduced visual motor skills integration is not related to type of VI.

Figure 4.34: Test of Visual Analysis Skills and age

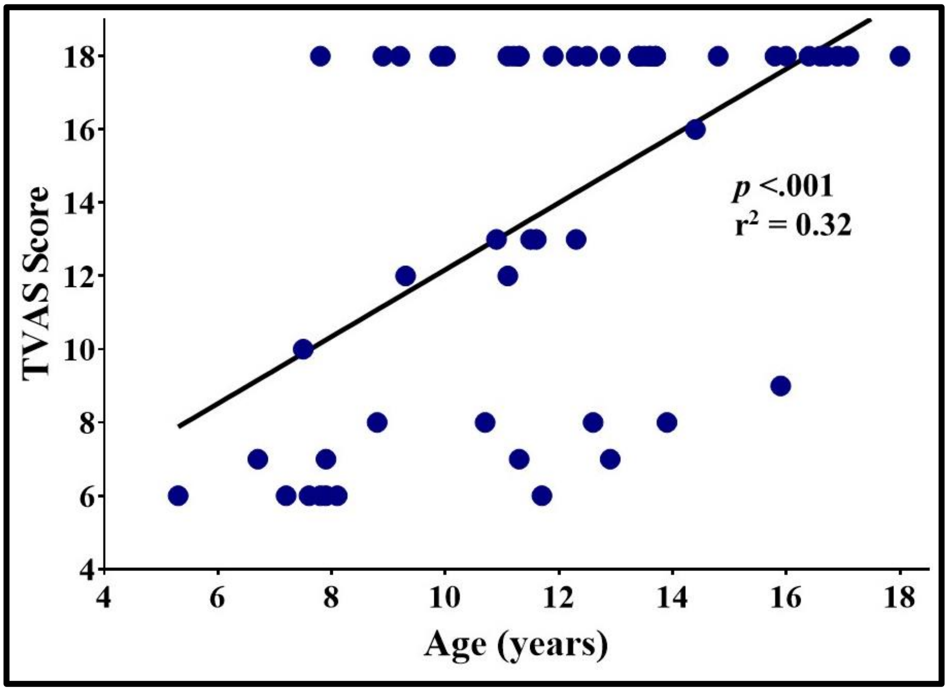

Figure 4.34. There was a significant (*p*<.001) positive correlation with scores on the Test of Visual Analysis Skills and age. However, there were some individuals that were not able to pass the 8th plate whilst another subset performed at a high level reaching the 18th and plate. This discrepancy suggests some differences in performance in subsets of students with a vision impairment.

4.10.2 Developmental Eye Movement Test

A total of (*n*=48) participants completed the DEM in NP and (*n*=34) in RP. There were significant negative correlations between NP ($r^2 = 0.31$, $p<.001$) and RP ($r^2 = 0.17$, $p=.02$) DEM scores with age as depicted in **Figure 4.35** and **Figure 4.36** respectfully. As expected, as age increased, the time to complete the DEM test decreased with NP ($r^2= 0.31$, $p<.001$) and RP ($r^2=0.17$, $p=.02$).

Figure 4.35: Development eye movement test and age (normal polarity)

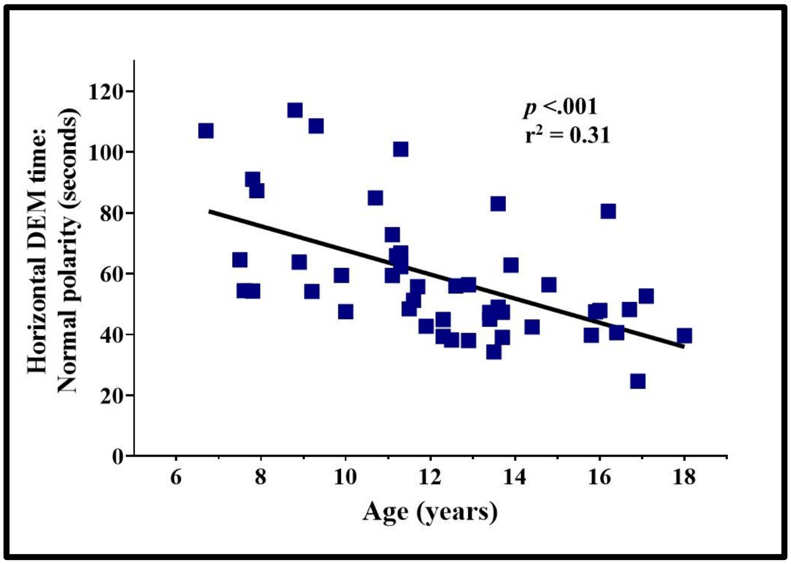

Figure 4.35. For printed numerals in normal polarity, the completion time (adjusted) of the Developmental Eye Movement test reduced significantly with the age (p<.001).

Figure 4.36: Development eye movement test and age (reverse polarity)

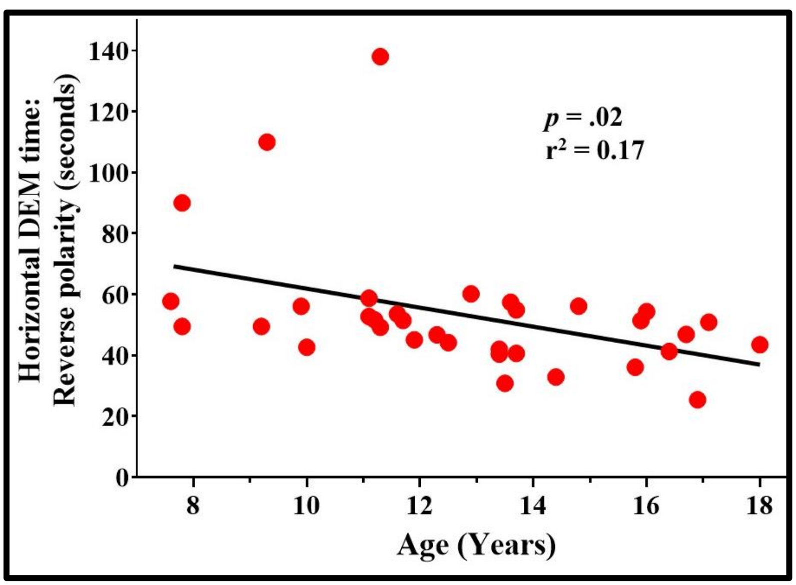

Figure 4.36. For printed numerals in reverse polarity, the completion time (adjusted) of the Developmental Eye Movement test reduced significantly with the age (p=.02).

The mean DEM horizontal test times were compared with reference ranges (available up to age of 13years (Richman and Garzia, 1990). Both NP and RP DEM times were slower than reference values, that ranged from 7.5 to 33.9 seconds for NP, and from 1.7 to 28.6 seconds for RP text. **Figure 4.37** and Figure **4.38** plot the mean times (NP and RP) for the DEM horizontal test for the participants with a VI against the mean reported reference times for children up to the age of 13 years respectively.

Figure 4.37: Mean developmental eye movement test time (normal polarity)

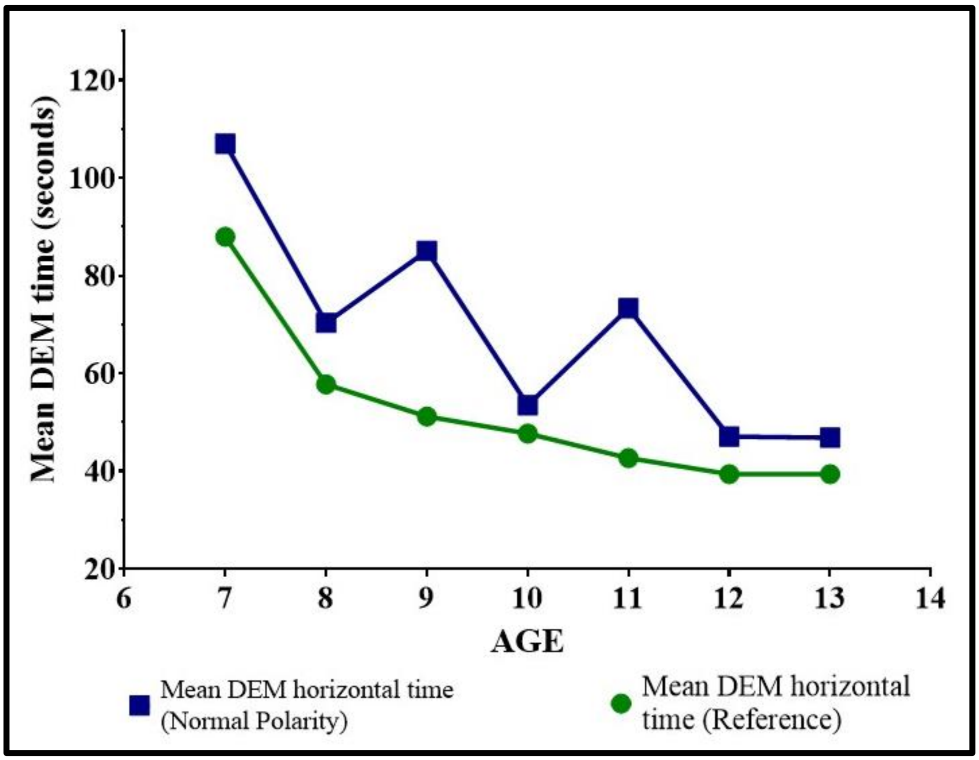

Figure 4.37. The mean normal polarity Developmental Eye Movement test times (seconds) in vision impairment compared to reference values reported by Richman and Garzia (1990) for children aged up to 13 years.

Figure 4.38: Mean developmental eye movement test time (reverse polarity)

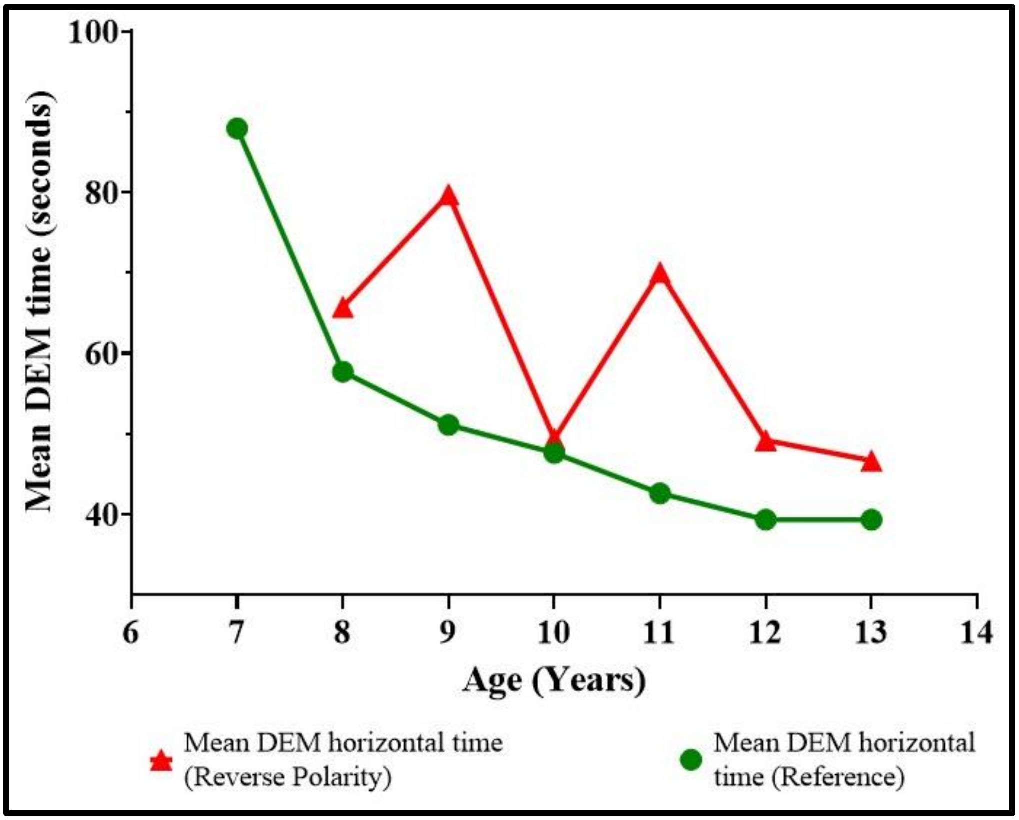

Figure 4.38. The mean reverse polarity developmental eye test times (seconds) in vision impairment compared to reference values reported by Richman and Garzia (1990) for children aged up to 13 years.

Both plots of mean DEM reading times for students with a VI demonstrate slower reading times when compared to the reference values up to age 13 years. The results are qualitatively similar to those observed with reading speed with printed text as illustrated in **Figure 4.39** that plots DEM NP reading time and NP screen text reading speed, side by side with age-appropriate reference values (Calabrèse et al., 2016; Richman and Garzia, 1990).

Figure 4.39: Comparison of reading printed, and screen reading text using normal polarity

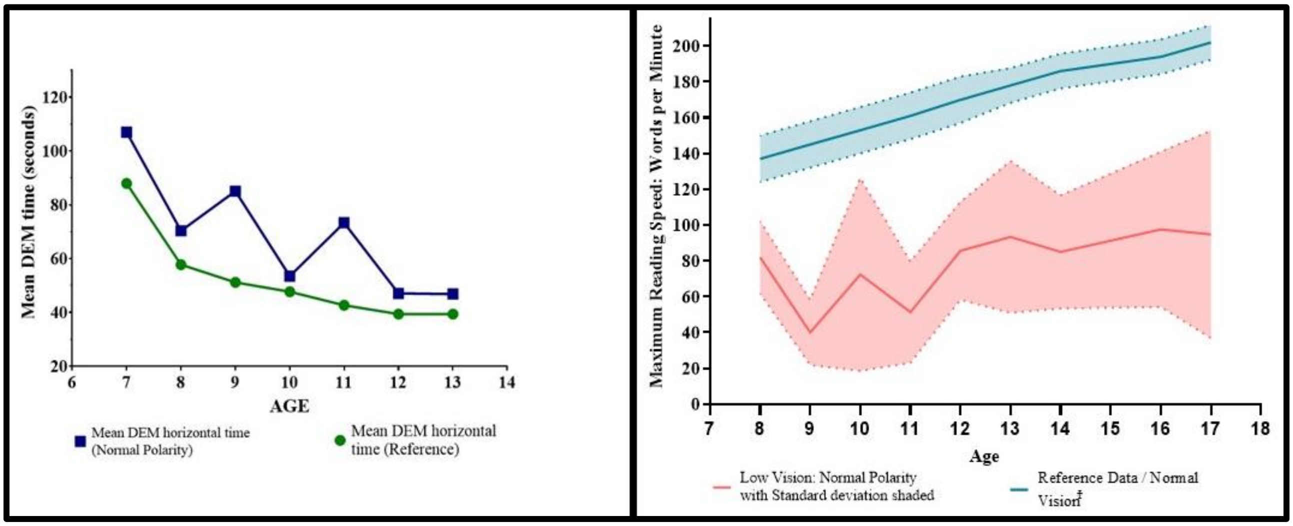

Figure 4.39. Plots of reading speed for comparison using the developmental eye movement test and screen text - both using normal polarity. The vision impairment group were slower in both tasks when compared to normally sighted age-appropriate reference values.

4.10.3 Test of Visual Analysis Skills and Developmental Eye Movement Test

TVAS results were then correlated with the DEM for both NP and RP text and a significant (p<0.001) negative correlation was observed for both conditions. This indicates that the students with a VI with better performance on the TVAS test of visual motor integration were also more adept and faster at completing the DEM under either text polarity condition. **Figure 4.40** and **Figure 4.41** show the correlations for the DEM and TVAS functional tests of vision.

Figure 4.40: Developmental eye movement test and test of visual analysis skills correlation (normal polarity)

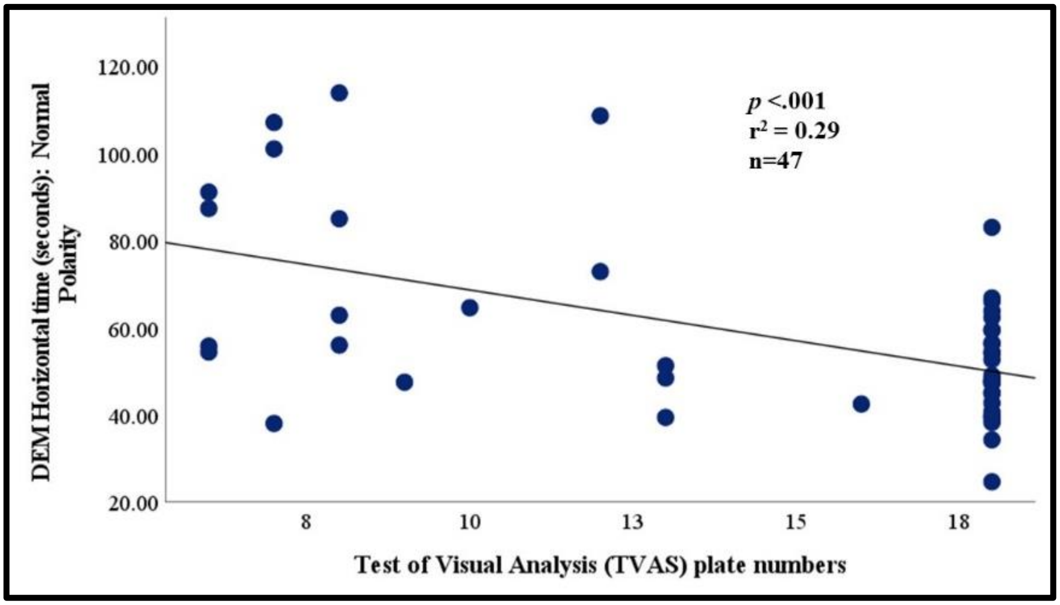

Figure 4.40. A significant negative correlation was found between the Test of Vision Analysis Skills (TVAS) plate number reached and the Developmental Eye Movement (DEM) test time in normal polarity (p<0.001), with the participants that finished the higher level TVAS plate also reading numbers faster on the DEM test.

Figure 4.41: Developmental eye movement test and test of visual analysis skills correlation (reverse polarity)

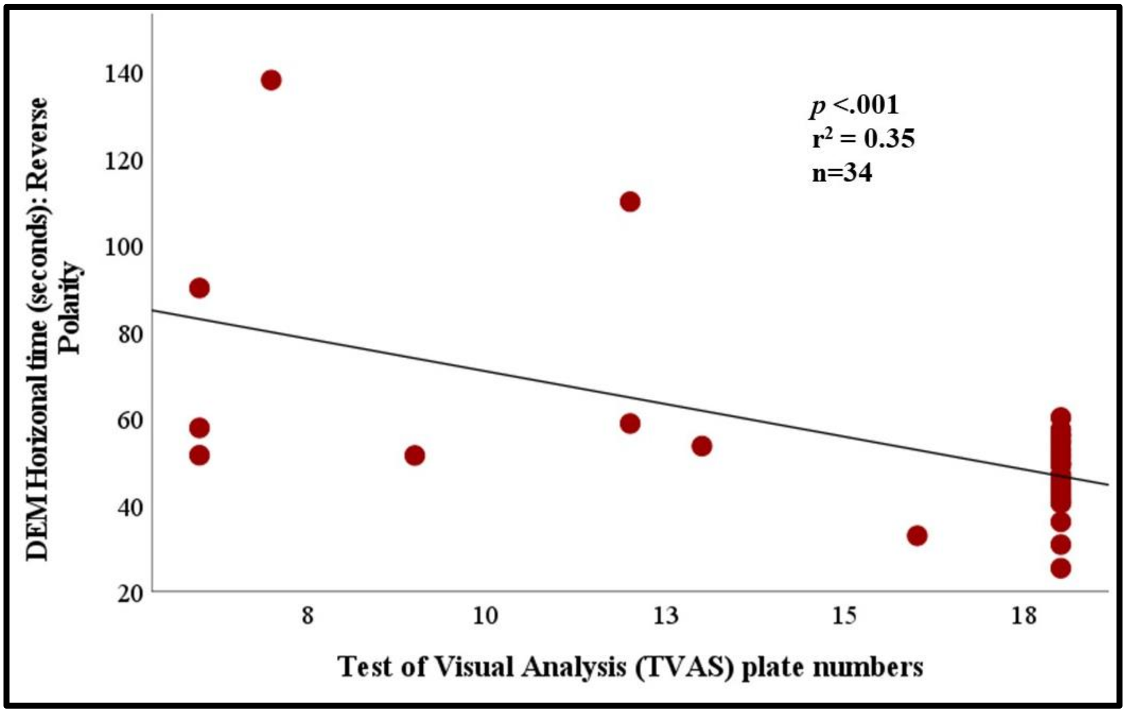

Figure 4.41. A significant negative correlation was found between the Test of Vision Analysis Skills (TVAS) plate number reached and the Developmental Eye Movement (DEM) test time in reverse polarity ($p<0.001$), with the participants that finished the higher level TVAS plate also reading numbers faster on the DEM test.

4.11 Supplementary Functional Tests

Within the functional vision assessment, some of the functional tests were used for informative purposes. At the conclusion of the assessment, all students, teachers, and parents received an in-depth report, highlighting the results of all tests, any deficits identified and detailed strategies to help within the classroom environment. An example of a recommendation report is shown in **Chapter 5.2** or **Appendix 9**.

Although some of the recommendations were specific and based around factors such as font size recommendations, reading time requirements, or polarity of text. Some of the assessment tests were used as informative, to increase knowledge of the student's vision functioning to enable enhanced support around more practical aspects of the student's learning environment.

4.11.1 Colour vision

Colour vision was assessed using a traditional Ishihara pseudoisochromatic colour vision test and a practical pen-top matching test. Of the students that failed the Ishihara, they were also the ones that were more likely to have difficulty with colour sorting. This practical test provided a "real world" visual example for teachers, and the students support teacher, around the understanding of colours that the student may have difficulty with. **Figure 4.42** shows some examples of poor colour sorting by students with a VI based on the pen colours.

Figure 4.42: Examples of poor functional colour matching using coloured pens

Figure 4.42. Examples of some of the results from pen-top matching during assessments, demonstrating to teachers which colours students may confuse. The aim of the test was for the student to be able to discriminate between the colour of the pen top lid and the pen, by placing the correct pen top colour with the coloured pen.

4.11.2 Cone adaptation test

The cone adaption test was an informative test to highlight how a student may take a longer time to adapt to different lighting levels. For example, the transition from a bright playground to a darker classroom, or if lights are turned off and on for video projectors in a classroom. This information can be particularly relevant to students on field trip or excursions, particularly if they are travelling in and out of buildings. **Figure 4.43** shows examples of VI students who failed to correctly sort all the red, blue, and white blocks correctly when the room lights were turned off and their cones dark adapted. Poor colour matching and sorting suggests poor cone adaptation function and likely difficulties when transitioning between changing luminance levels.

Figure 4.43: Examples of some results from the cone adaption test

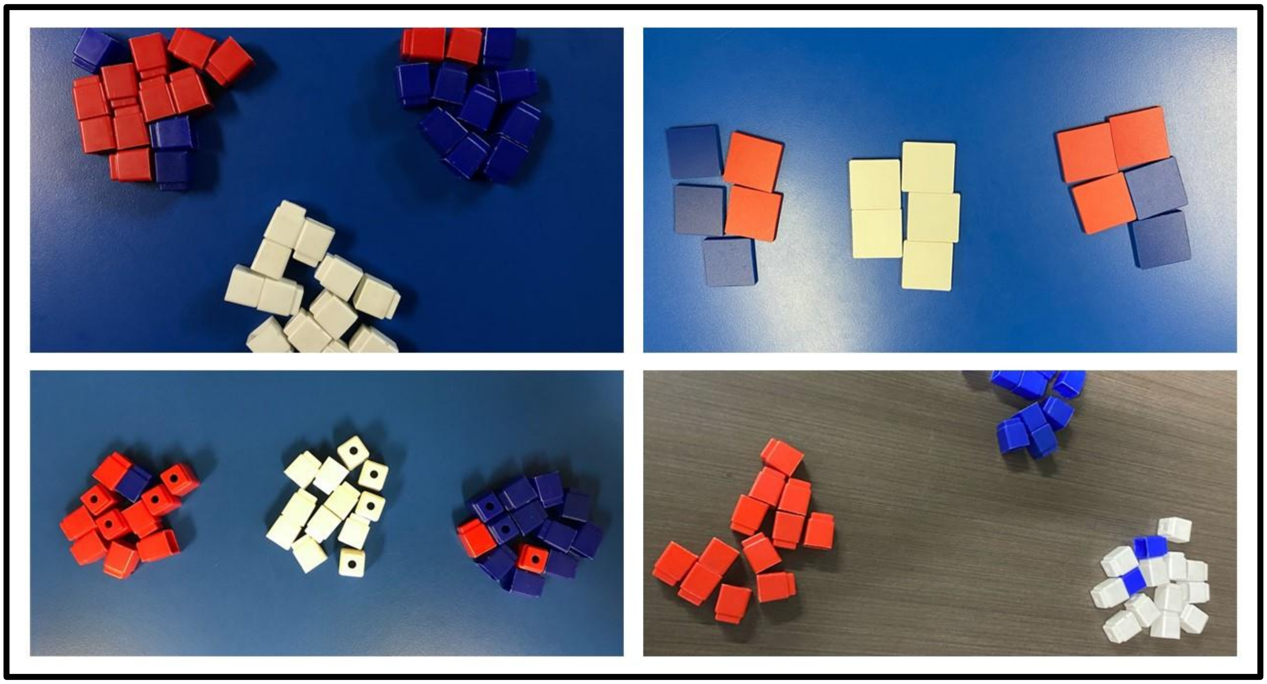

Figure 4.43. Some students attempt at colour sorting the red, blue, and white blocks during the initial dark adaptation time. For these students incorrect sorting of the coloured blocks suggests poor dark adaptation in the cone pathways and potential difficulties transitioning between different luminance levels.

CHAPTER 5 : CASE STUDY

This study underscores the significance of customised functional visual assessments in influencing individual outcomes. Within South Australia, these assessments are pivotal in facilitating student support. They provide an in-depth understanding of the visual capabilities of students with VI, thereby enabling the customisation of support mechanisms to augment their educational experiences. Assistance is rendered through a detailed report (**Appendix 9**) which is extensively discussed with the specialist teacher. This discussion facilitates a comprehensive understanding of the students' needs and requirements, optimising support for accessibility in their classroom setting.

This case study, reports on the individual impact that a functional vision assessment and the subsequent modifications in the educational setting of the individual can provide. An informal interview further elucidated the practical impact of these interventions on her classroom learning experience. This case study further illustrates the necessity of comprehending a student’s visual abilities to efficaciously bolster their educational and learning experience. Through a thorough functional vision assessment, educators and the student's support team can identify areas of difficulty and devise individualised strategies and solutions to the student's needs. These measures can be instrumental in fostering active engagement and achievement in the classroom. Functional vision assessments are integral to establishing an inclusive educational environment for all students with VI.

This chapter presents a case report derived from the following published work

Clinical and Experimental Optometry

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Cone dystrophy, childhood vision impairment and education: are clinical measures of visual function adequate to support a child through education?

Lynne Loh, Anna Gatsios, Mallika Prem Senthil & Paul A Constable

Loh L, Gatsios A, Prem Senthil M, Constable PA. Cone dystrophy, childhood vision impairment and education: are clinical measures of visual function adequate to support a child through education? *Clin Exp Optom*. 2022;105(7):774-777. doi:10.1080/08164622.2021.1971044

This case report describes a 13-year-old girl with a cone dystrophy who had just transitioned from a specialist VI school into a large mainstream high school in South Australia. It investigates differences in the standard visual function tests and compares these metrics to her visual performance, including self-reported impact of the vision impairment within the school environment for her.

5.1 Case Study

The case was a 13-year-old female, who was delivered at thirty-five weeks and at a routine post-natal twelve-week check, nystagmus was noted. At six months, cone dystrophy was diagnosed based on visual electrophysiological measures. She has a distant family history of Retinitis Pigmentosa on her maternal grandfathers' side. No genetic testing has been conducted to date. A comprehensive assessment of visual function was performed to evaluate her current level of performance, and she was interviewed regarding self-reported visual ability, using the Cardiff Visual Ability Questionnaire for Children (Khadka *et al.*, 2010), and the impact it has on her educational learning.

5.1.1 Clinical Findings

Her refractive error was right eye: -2.25/-4.50x15 and left eye: -1.75/-2.00x160. VA was measured using the Freiburg Visual Acuity Test (FrACT) (Bach, 1996). Crowded VAs were Right:1.04 LogMAR ($6/60^{-}$) and Left: 0.98 LogMAR (6/48). She has manifest nystagmus, with a left preference alternating exotropia.

A central 30-2 threshold visual field test (Humphrey HFA-II, Carl Zeiss, Oberkochen, Germany) revealed generalised reduction in sensitivity for the right eye -7.60 dB and the left eye -8.70 dB, with a high false negative test index reported in **Figure 5.1**. Fundus photography, fundus autofluorescence and macular optical coherence tomography were performed using the Zeiss Cirrus 5000 (Carl Zeiss, Oberkochen, Germany). Optical coherence tomography and retinal photography revealed retinal atrophy with inner retinal thinning and focal macula hyperfluorescence (left greater than right) as shown in **Figures 5.2.**

Figure 5.1: Visual field results

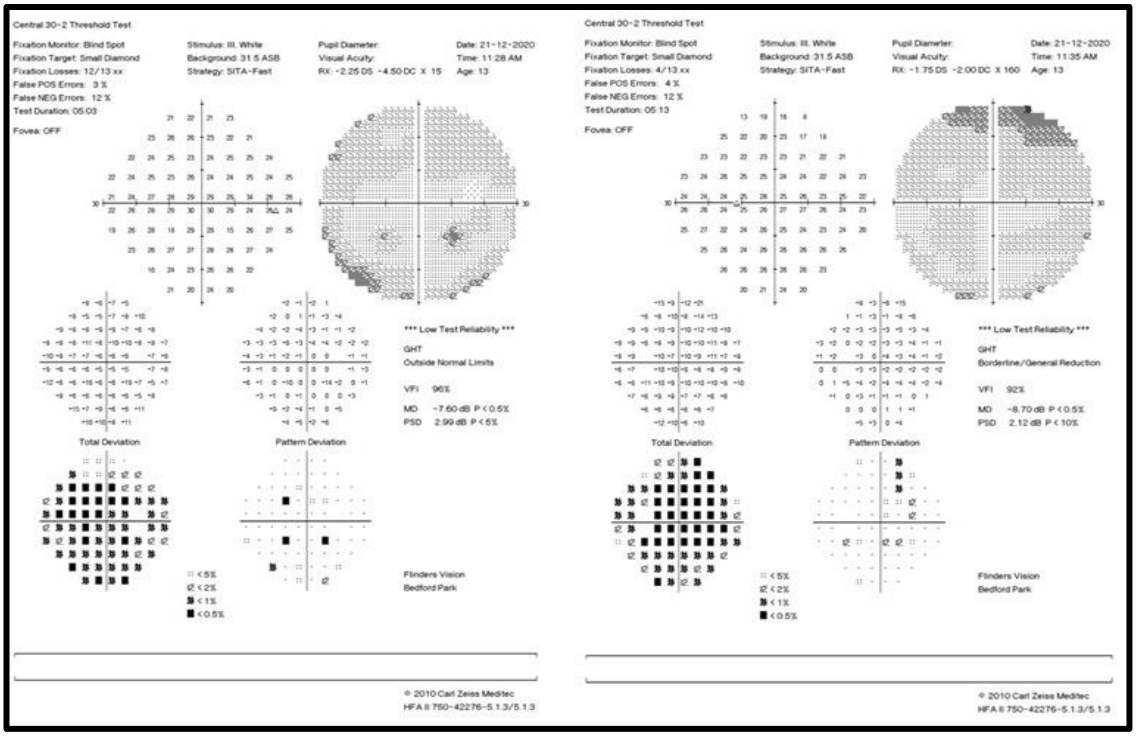


Figure 5.1. Visual fields performed on the Humphrey Field Analyser-II revealed a significant ($p<.05$) generalised depression for the right eye of -7.60dB and left eye – 8.70dB. There was no marked constriction in the fields with an overall visual field index of 96 % and 92% for the right and left eyes respectively.

Figure 5.2: Fundus and FAF photographs, and macula scans

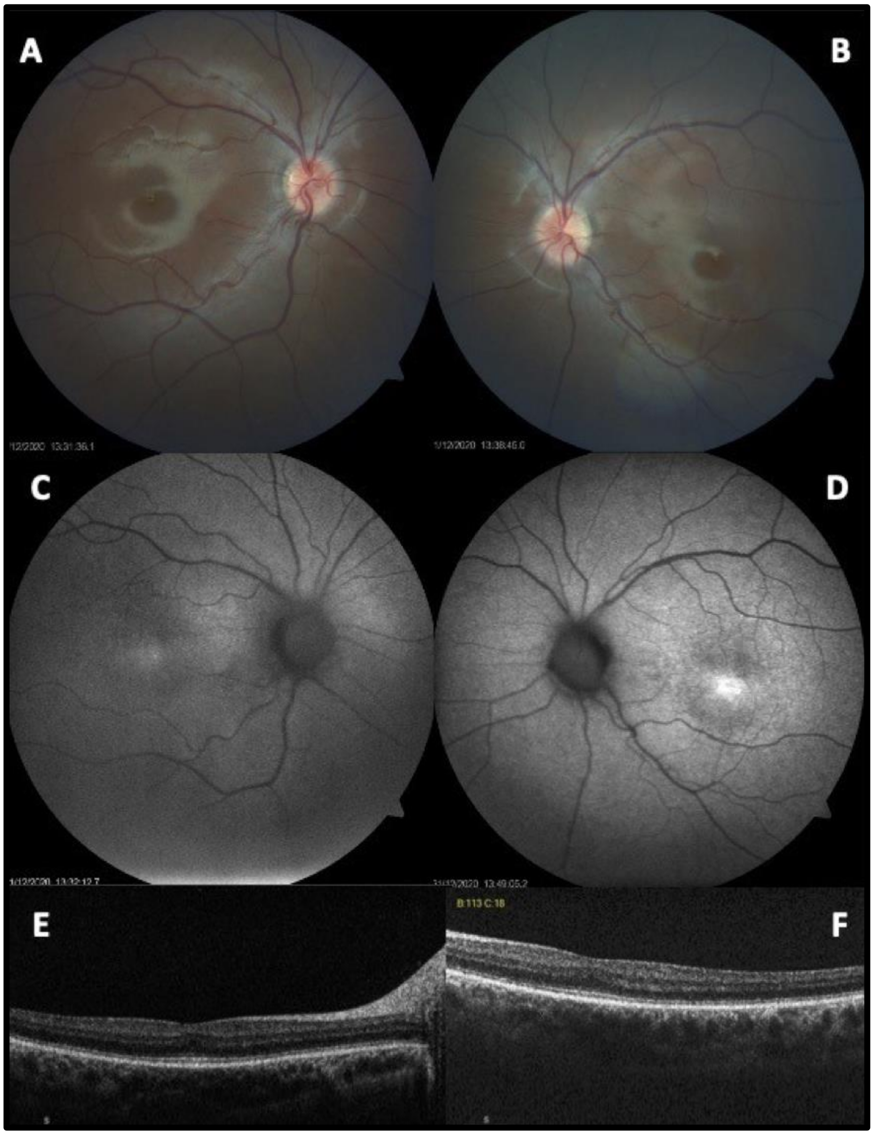


Figure 5.2. Figures A and B show the right and left eye fundus photographs with no marked retinal anomalies. Figures C and D show fundus autofluorescence with hyperfluorescence (left greater than right) indicating retinal pigment epithelial stress. Figures E and F show macular scans with normal foveal architecture.

Electrophysiology

Full field light- and dark-adapted electroretinograms were recorded using the six-step ISCEV Troland protocol in the RETeval with light adaption first followed by 20 minutes dark adaptation. Two repeats were performed in each eye with average results reported with the 95th centile upper and lower confidence reference range (*n*=50) typical children aged 3.7 to 16 years). The DA0.01 b-wave amplitude was: RE 44.3 μV and LE 35.5 μV (95th centile CI 28.7 to 81.5 μV). DA3 b-wave amplitude (RE 85.5 μV and LE 73.6 μV) 95th centile CI 21.3 to 136.1 μV) and a-wave amplitude (RE -33.7 μV and LE -44.4 μV) 95th centile CI (-31.5 to 73.2 μV). The DA10 b-wave amplitude was: (RE 66.0μV and LE 93.5 μV) 95th centile CI (22.7 to 153.7 μV) and a-wave amplitude (RE -49.6 μV and -67.5μV) 95th centile CI (-30.0 to -65.4 μV). The light-adapted responses were abnormal indicative of retinal cone dysfunction with the LA 3 b-wave and a- wave amplitudes being non recordable. The 30Hz flicker amplitudes were RE 2.2 μV and LE 2.3 μV) with the 95th centile being (16.5 to 70.5μV). Representative response for the right and left eyes with reference response are shown in **Figure 5.3.**

Figure 5.3: Electroretinogram waveforms

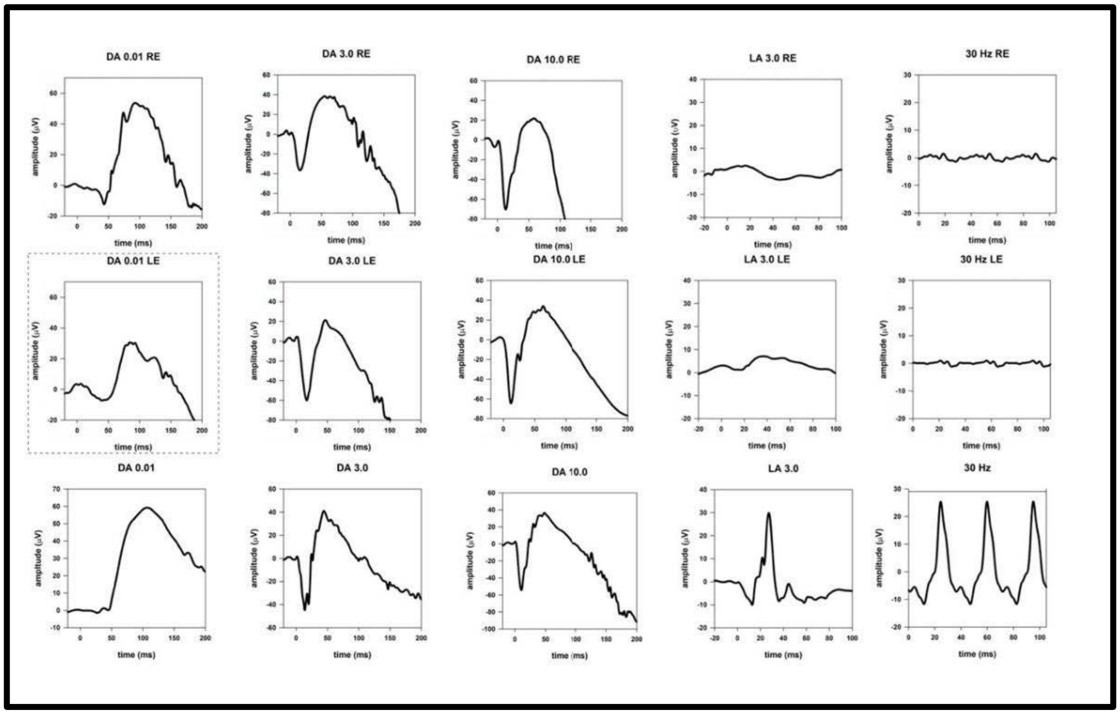


Figure 5.3. Full field electroretinogram waveforms for the right (top) and left (middle) panels recorded under dark- and light-adapted conditions. Bottom panel shows a typical waveform for right to left the dark adapted 0.01, 3 and 10 cd.s/m^2 and the light-adapted single 3 cd.s/m^2 and 30Hz flicker responses. The case showed absent cone responses in the right and left eye with near normal dark-adapted waveforms.

5.1.2 Functional Vision Tests

Binocular crowded VAs were measured under differing ambient light levels using. Under photopic illumination (450 lux) a VA of 0.85 LogMAR (~6/45) was measured, which improved under mesopic illumination (10 lux) to 0.78 LogMAR (~6/38). Resolution threshold contrast sensitivity (CS) was measured using FrACT Contrast C (Bach, 1996) and revealed a reduced measure of 0.71 logCS compared to a typical value of 1.93 logCS. Binocular colour vision, using a standard sized

D15, revealed a Tritan defect as previously reported in macular dystrophies (Bresnick *et al*., 1989) and shown in **Figure 5.4**.

Figure 5.4: Colour vision testing results.

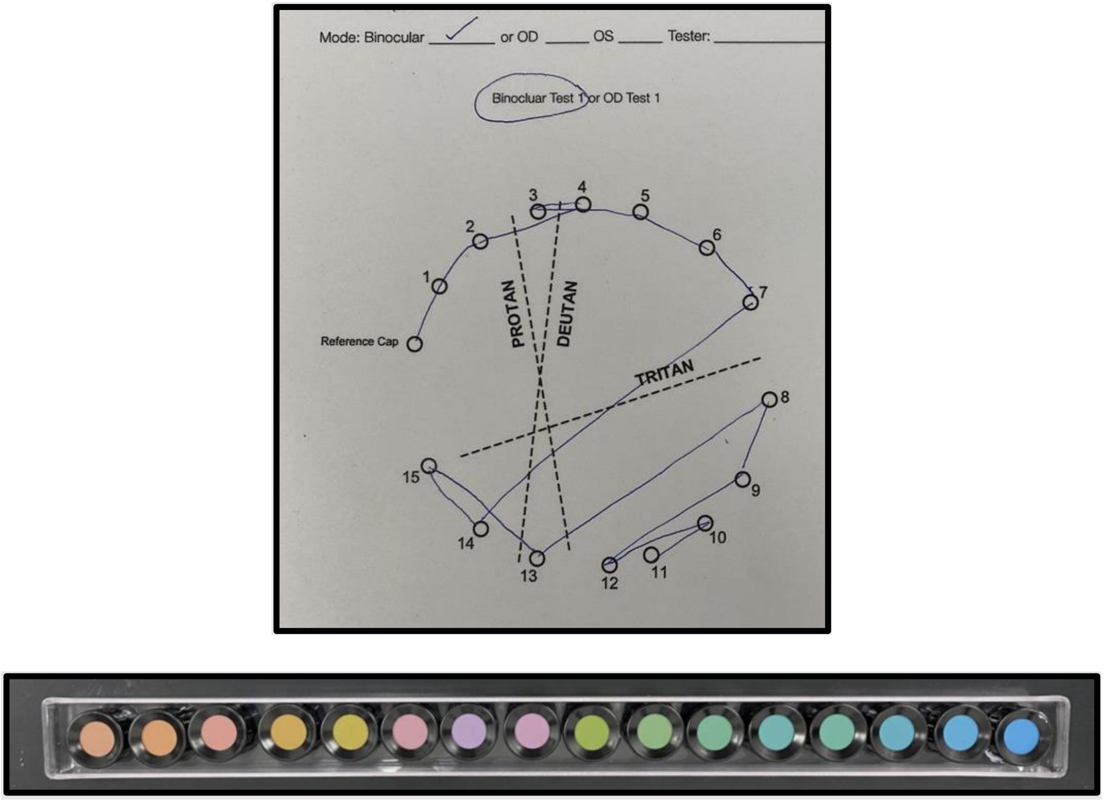


Figure 5.4. Results of the D15 colour vison test performed under normal room lighting binocularly revealed a Tritan defect.

Reading Performance

Reading analysis was performed using the MNREAD Application (Calabrèse *et al*., 2018). MNREAD was designed to assess aspects of reading, such as reading acuity (smallest print size that can be read), critical print size (the smallest font size read at maximum speed), and maximum reading speed. Reading analysis was performed for both normal (black on white) and reverse polarity (white on black).

All reading measurements were taken at 40 cm. Using NP, she achieved a reading acuity of 22-point (0.90 LogMAR) and CPS of 29-point (1.02 LogMAR). With RP, she achieved a smaller reading acuity of 15-point (0.73 LogMAR) and a CPS of 23 point (0.92 LogMAR). Additionally, at the recommended minimum font size of 23-point print with RP, her reading speed was 92.1 WPM, compared to 56.8 WPM with NP. See **Figure 5.5** and **Table 5.1**.

Table 5.1: Reading analysis results

Reading Test Parameters at 40 cm	Normal Polarity	Reversed Polarity
Reading acuity LogMAR (Print size)	0.90 (22)	0.73 (15)
Critical Print Size LogMAR (Print size)	1.02 (29)	0.92 (23)
Corrected Reading Speed at 23-point print (words per minute)	56.8	92.1

Table 5.1. Summary measures of reading ability with normal and reverse polarity text.

Figure 5.5: Reading analysis output plot

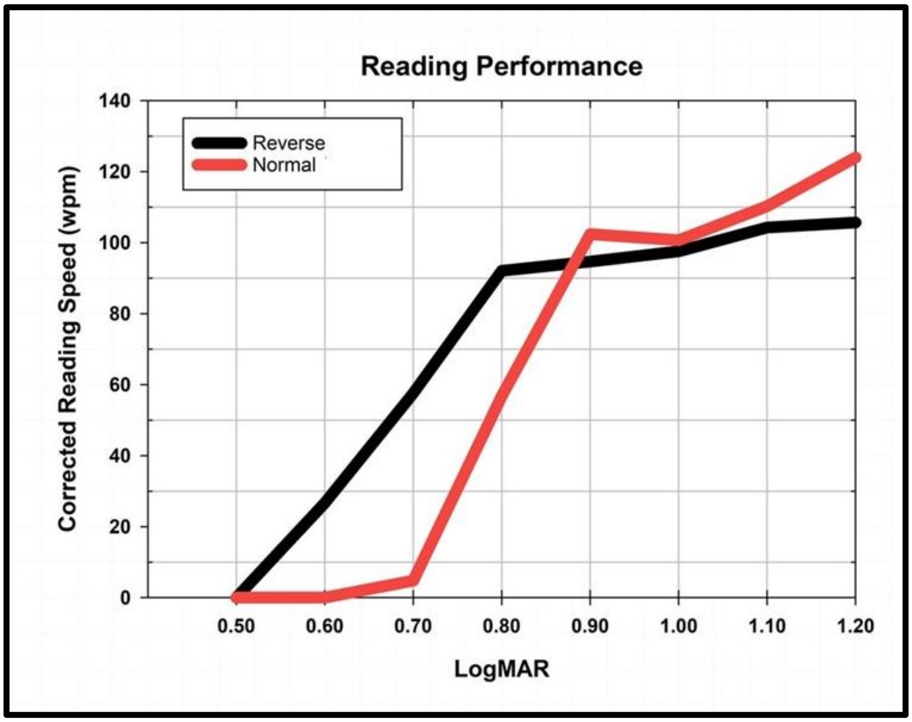


Figure 5.5. The effects of reversed polarity (black line) and normal polarity (red line) on reading speed. The sharp drop in reading speed is apparent once critical print size is reached. With the reversed polarity she was able to read smaller text and critical print size was smaller.

5.2. Recommendations to the student's parents and educators

The following contains a sample of some of the information and recommendations that were given to her parents and educators to assist her classroom accessibility (the students name has been replaced with "her" or "she").

5.2.1 Recommendations

Vision

Her 6/45 acuity means that she can differentiate detail at 6 metres, that a person with normal (6/6) vision would be able to see at 45 metres. When room illumination was reduced and VA re-tested, her vision improved to 6/38. This is not unexpected given her diagnosis, and her vision performance will be better, and more comfortable, in reduced room lighting.

She has the use of an iPad in the classroom and providing her with electronic worksheets and documents allows her to enlarge them to a more comfortable font size. The use of technology allows students with a VI to enlarge materials to a size which is comfortable for them to enable sustained work. This size may vary depending on visual fatigue and tiredness. Using an iPad to photograph the board and enlarge detail in front of her is another independent accessibility option.

Nystagmus

Nystagmus is the uncontrolled erratic movement of the eyes. Often there is gaze position called a “null point”, this is where the nystagmus movement is the slowest and vision will be clearest. She demonstrated low amplitude (small movement) nystagmus in the primary position (straight ahead). She is therefore best positioned centrally in a classroom and as close to the front as possible. She should also be positioned with an unobstructed view of the board in a class so that she is able to photograph detail and enlarge it if necessary.

Nystagmus can also worsen in bright light or glare and can be exacerbated by flickering lights (such as overhead fluorescent tubes). She is also extremely sensitive to light sources and glare and requires a darkened environment for comfort. She should be positioned to avoid any direct or indirect glare sources (such as sun shining in the window or reflected from a board). If she uses a white reflective desk, then black card to put over her desk can significantly reduce reflected glare and discomfort. An anti-glare cover on her iPad and phone with also help to reduced reflected light and glare she may experience from a screen.

Contrast Sensitivity

Contrast sensitivity is the ability to detect an object against its background. A high contrast task would be black on white, compared to a lower contrast task, for example yellow on white. She has reduced contrast sensitivity compared with a child the same age with normal vision which, in combination with her glare sensitivity, may be worse when she is in a bright environment such as the playground. As demonstrated on VA testing her visual performance improved when room lighting levels are lowered.

When writing on class white boards, the use of higher contrast pens such as black or dark blue are easier to see. Classrooms floors should also be kept clear of unnecessary clutter as low contrast objects, such as bags and jackets, can cause tripping hazards.

Colour Vision

She has difficulty differentiating certain colours which will appear the same to her. This should not significantly impact her functionally, but the use of colour as a descriptor is best avoided. The use of colour to differentiate critical information on graphs or tables is also best avoided unless bright primary colours are used, as she may perceive certain colours as the same and this can lead to important information being missed or misinterpreted.

Reading

Reading analysis at a 40cm working distance demonstrated a minimum print size reading ability of 22 point with normal polarity (black writing on a white background). During reading, as we reach the limit of what we can see, reading speed begins to reduce rapidly. CPS is the largest font size before reading speed begins to decrease. Her critical print size was identified at 29-point with normal polarity. This means for prolonged reading; font size should not be any smaller than this when given in printed material. She can read smaller font if she brings it closer, which effectively magnifies the print (the closer print is, the larger the image on the retina). However, for sustained and extended near work, bringing print closer demands an increase in effort from the visual system and results in visual fatigue and tiredness. It can also result in headaches at the end of the day.

With RP (white text on black background) she achieved a smaller minimum print size of 15-point and a critical print size of 23- point. Additionally, at the recommended minimum font size of 23-point print with RP, her reading speed was 92.1 WPM, compared to 56.8 WPM with NP. This information means that RP is a more comfortable reading medium for her to use and is not unexpected given her vision diagnosis. Because of this, documents in electronic format would be preferable so that she is able to enlarge the font to a comfortable size and change the polarity (colour reversal) on her electronic device.

According to previously published data, a 13-year-old child's average reading speed is approximately 170 WPM. Her MRS with recommended RP font was 92 WPM. This indicates that if she is given a passage of text to read, she may require almost twice as long to read it than a normally sighted child. This information will be particularly relevant to tests or exams.

Visual Fields

She demonstrated an overall loss of sensitivity (clarity) of her visual fields. She is currently receiving orientation and mobility instruction to increase independent safe travel. Maintaining classroom floors clear of obstacles, particularly low contrast, can also help to reduce unnecessary accidents.

Electrophysiology

When light enters an eye and hits the retinal receptors, this light is converted into an electrical signal which is carried to the visual cortex via the optic nerve. The ERG measures the mass electrical response of the retinal receptors to light, using a small electrode (sticker) placed on the lower eyelid. When an ERG is performed when the eyes are light adapted, it is measuring cone (photopic vision) function. It is then performed after 20 minutes of dark adaptation to measure rod (scotopic vision).

Her ERG recorded a minimal cone response to light adapted flicker but a near normal ERG for dark adapted vision. She therefore relies mainly on rod function for vision, which explains her extreme sensitivity to light and is consistent with her ability to see better in reduced illumination and her loss of colour vision. Her vision is most comfortable in reduced illumination. If she is not in a darkened classroom, then she will benefit from sunglasses when indoors – particularly if the classroom is well lit. She will find transitioning from a dark to light environment uncomfortable and her vision will worsen. This is particularly important during field trip or excursions, and she will require extra time or support to ensure safety while mobilising around in unknown environments. Although she is competent with the use of a long cane, unknown busy environments present additional difficulties.

Her eye condition can be progressive and a deterioration in vision is possible over the following years. If a change in her vision or class performance is noticed, then a further functional vision assessment would be recommended to update her classroom accessibility requirements. Encouraging independent accessibility will enable sustained access the classroom content. It is recommended that she predominantly use electronic documents which she can enlarge to a comfortable size and reverse the polarity (colour inversion). Continued practice of audio-based learning is also recommended if her vision deteriorates and results in vision-based tasks becoming difficult.

Summary

She has reduced vision, manifest nystagmus, and difficulty with glare. All these factors can contribute to significant visual fatigue toward the end of the day, particularly when performing visually demanding tasks. Continued use of technology is essential as she transitions through education. Electronic documents are preferred so she can adjust font to a comfortable size - which may be larger toward the end of the day. Electronic documents will also allow her to use audio technology to read material to her. This can help reduce the visual fatigue she will experience towards the end of the day, which may be more evident in future years as she progresses through school years and her workloads increase. Previous published research highlights that the academic gap begins to widen in middle school if students with a vision impairment are not provided with adequate tools to effectively access the school curriculum independently. It is also important that she continues learning the skills to independently access class material. Enhanced independence skills for students with a vision impairment has also been shown to improve health related quality of life at school.

5.2.2 Summary

This case highlighted the benefits of using functional and performance-based measures of visual ability for children in education. Results from her clinical measures were consistent with a previously diagnosed cone dystrophy.

Childhood VI is often categorised, and support levels determined according to VA and visual fields, but by providing additional measures of visual performance such as reading speed, print size requirements or the effect of contrast, a more holistic picture of the individual’s abilities and needs can be utilised to improve their learning performance within the classroom.

Results from functional vision tests were used to inform class teachers of expected accessibility deficits and strategies to help overcome these. Recommended adaptions included required print size (including recommendations for electronic documents with RP, contrast requirements, lighting requirements based on VA measures from different ambient lighting, information, and management of visual fatigue due to nystagmus, impact of colour vision deficit, and extra time requirements based on reading speeds.

As detailed in the introduction to this thesis in **Chapter 1.5** reading, writing, and literacy skills are essential foundations to learning, and access to appropriate print size material can have a significant effect on a child’s ability to learn at the same rate as their peers (Corn *et al*., 2002). CPS can be used to determine an appropriate print size to enable optimum reading capacity. This students CPS was 29-point with NP, which could then be used to inform her teachers and carers of the minimum font size required to facilitate comfortable reading for extended periods. She was able to read smaller sized print if it was brought closer, effectively magnifying the print. However, for sustained and extended near work in the classroom environment, using a closer working distance is difficult to sustain. When reading analysis was performed using RP, she was able to read smaller print size at a faster rate, indicating better reading efficiency with RP text. This information informed teachers that her preference for learning material was electronic documents, so she was able to enlarge the font to a comfortable size and use RP text.

MNREAD charts have published reference baseline measures of reading speeds (Calabrèse *et al*., 2016), which enables the provision of advice regarding time allowances for class work and assessments. In South Australia, this recommended print size in combination with other factors, such as reading speed, impact of visual fatigue and likelihood of disease progression, is used to determine long term provisions for support. Long term support includes introduction to Braille, audio-based learning and screen reading software programs (i.e. Job Access With Speech) and Orientation and Mobility requirements to ensure future independence.

5.2.3 Interview with the student

During a 1:1 interview with the student, she acknowledged a more comprehensive assessment of visual function and performance had helped to improve her accessibility to educational materials, and the positive impact it had made transitioning to secondary education. She commented that:

"*Because I have trouble with bright light and glare, the polarity is reversed on electronic documents so it's easier, and more comfortable, for me to read."*

"I am allowed extra time for homework and exams because it takes me longer to scan and read, especially if I have a lot of reading to do."

These comments supported the use of RP text for her and reading speed analysis provided a quantitative measure that enabled her to be given the appropriate extra reading time for her work.

This case highlights the impact of specialist support and the need for investigative assessments which include functional aspects of VI, such as print size, reading speed, reading accessibility index, contrast requirements and the impact of NP or RP text, so adequate provisions can be made for students to access their educational needs. While vision function tests are important to confirm diagnosis, subsequent assessments should be performed to assess the individual's functional visual performance which may not correlate directly with clinical tests such as visual acuity and visual fields. These measures can be used to help provide information around optimum accessibility requirements and future requirements that may be needed, such as Braille or audio-based technology. This is especially important for students transitioning to high school where students with VI can face additional accessibility obstacles and have difficulty accessing learning material at the same rate as children without a VI (Corn *et al*., 2002).

Student comments on her vision impairment

Below are the responses to questions posed by Lynne Loh to the student in relation to the impact of her vision on her educational opportunities.

How do you feel that your vision impairment affects your schooling?

"I manage ok. I have had a lot of help from SASSVI."

"I use my laptop for most things and can enlarge things so I can see them. I can also listen to documents if I'm tired. If I use print, it is enlarged so I can see it easier, and it doesn't cause eyestrain."

"Because I have trouble with bright light and glare, the polarity is reversed on electronic documents so it's easier, and more comfortable, for me to read."

"I am allowed extra time for homework and exams because it takes me longer to scan and read. Especially if I have a lot of reading or research to do."

How difficult was it to make new friends when you transitioned to high school?

"It was ok, nobody has really asked me about my vision yet."

"It was easy transitioning to high school. SASSVI arranged for extra transition days so I could get used to the school and an Orientation and Mobility Instructor helped me work out how to get around school before I started."

Is there anything that you would like to do, but can't, because of your vision impairment?

"I would like to know what everything looks like with normal vision."

"I wish I could have one day where I could see like everyone else does, to see what normal vision is like."

If you could change any aspect of your vision, what would it be?

"I just wish I could see better."

"I would like to be able to go outside and the sun doesn't hurt my eyes."

"I wish I could drive a car when I'm older."

5.3 Assessment Feedback

Following the case study and the discussion with her around the impact the assessment had upon her classroom learning, it was felt that obtaining feedback from students with a VI would provide valuable insight into how the specific challengers impact their classroom learning, but more specifically, how the adjustments following the functional assessment had impacted the way they learned within the class.

5.3.1 General feedback from students

Due to time constraints, a small selection of students were selected from the Statewide Support Service. A total of 14 students (10 male, 4 female) were asked for feedback on the interventions that were designed to improve their access to educational resources in primary (year 3-6), secondary (year 7-9) and senior (year 10-12). Demographics and primary pathology diagnosis are detailed in **Table 5.2** and **Table 5.3** respectively.

Table 5.2: Characteristics of included participants for feedback

	Mean ± SD
Age (years)	11.9± 2.4
School year/ grade	6.2 ± 2.5
Binocular visual acuity (logMAR)	1.15 ± 0.58
Reading acuity (logMAR)	0.92 ± 0.23 normal polarity 0.91 ± 0.20 reverse polarity
Reading speed (words per minute)	74.92 ± 39.15 normal polarity 80.61 ± 33.75 reverse polarity
Critical print size (logMAR)	1.05 ± 0.19 normal polarity 1.06 ± 0.22 reverse polarity
Contrast Sensitivity (logCS)	1.13 ± 0.38

Table 5.2. Demographics of included participants: age, school year, binocular visual acuity, reading acuity, reading speed, critical print size and contrast sensitivity. All measures are mean ± standard deviation (SD).

Table 5.3: Primary diagnosis in students providing feedback

Primary Diagnosis	**Number of students (*n* = 14)**
Retinal Dystrophy	5
Albinism	4
Optic Nerve Glioma	2
Congenital Glaucoma	1
Optic Nerve Hypoplasia	1
Optic Neuropathy	1

Table 5.3. Primary pathology diagnosis and number of students included for interviews.

5.3.2 Feedback from students

Informal discussions were conducted using a framework of question designed to facilitate an open and productive dialogue. The questions were constructed to enable students to be comfortable sharing their thoughts openly. They were all advised that the feedback given would not be passed on to their class teachers but were simply to understand how the assessment and subsequent support had helped (or not helped) within the classroom environment. They were encouraged to speak freely and report on anything related to their classroom learning, whether they felt it was relevant or not.

Feedback Questions

The following questions were used as a guideline only, but most discussions became open dialogues around school and home. Questions were reworded if required, depending on the age of the student.

What did you learn from the functional vision assessment?

- Did you read the assessment report, and did you understand it?
- What did you learn about your vision?
- Did you learn anything different about your vision - what was it?

Tell me about all the changes that have happened in the classroom (or at home) since the functional vision assessment?

- What things do you do differently in the classroom to help you learn or access class materials?
- How did the print size you use change – how has it helped?
- What changes were made to time requirements or guidelines and how has it helped?
- What changes or adjustments have there been around workloads?
- What technology changed for you - how did this help?
- What changes have there been at home since the assessment - homework for example?

How do you think the functional vision assessment has changed the way you work in the classroom?

- How are you managing with completing classwork, assignments, homework? How has this changed since the assessment?

- What do you still find difficult to access in the classroom or at school?
- What would you still like to change if you could?
- How are you managing with visual fatigue/headaches?

How have the changes made you feel about school?

- Has it changed how you feel about school - do you enjoy it more, less or unchanged?
- Do you find working in the classroom or at home easier, harder, or just the same?
- Do you think it has changed school for you socially? Do you have more time with friends?

5.4 Student Feedback

5.4.1 The following is a selection of quotes from students

What did you learn from the functional vision assessment?

"I learnt that one eye is more sensitive to light than the other, so I make sure I'm in the right place in the classroom and cover that eye with my hat more."

"I'm happier asking teachers for help because I can explain better why I need it."

"I really like that I now understand why my vision isn't working and I can explain to other people why I need help."

"Understand vision condition better and why I find glare difficult."

"I understand why my peripheral vision is better and why I struggle in bright light."

"I know a lot more about my vision and I like that I can explain to other people about it and the problems that I have."

Tell me about all the changes that have happened in the classroom (or at home) since the functional vision assessment?

"Print was made larger – which is easier, but I prefer electronic documents so I can enlarge them."

"All my work was changed to reverse polarity, if I look at white paper my eyes get really tired and sore after a few minutes."

"My work was changed to reverse polarity and that has helped."

"I can have extra time to finish work if I need it."

"I get all my work in electronic documents so I can adjust it and they are easier to see."

"I am more comfortable advocating for myself and asking for help."

"I know my limitations better and it has made school easier."

"My parents changed all the blinds at home to help - so it's not as bright in my room."

"I'm happier asking for extra time if I need it."

How do you think the functional vision assessment has changed the way you work in the classroom?

What changes had occurred in the classroom since the assessment?

"I stopped using print because it was too slow, I just use JAWS now and I can work a lot faster."

"I take a break if I'm tired or use audio technology – otherwise I know I will get a headache at the end of the day."

"I get digital copies and that has helped the most."

How have the changes made you feel about school?

"I find schoolwork easier and enjoy it more."

"I don't find much difficult now - only if it is very visual - then I ask for help."

What would you still like help with?

"Relief teachers are difficult because they don't understand my vision and it is hard to ask for help."

"Sometimes the blinds in the classroom don't block out enough light."

"Outdoor sports are difficult sometimes and not all teachers understand."

"I wish I didn't have white hair."

"I get really tired at school sometimes."

"Maps are really hard to look at if they are complicated."

5.4.2 Feedback Themes

Although the number of student discussions were limited due to time restraints. Despite being a small group, feedback given was similar amongst the students. Most VI students mentioned that they had been given extra time following the assessment or that classroom materials had been changed, including font size or the polarity of screens. The most common accessibility adaptation among students was the increase in electronic documentation that was given to them so that they were able to adapt the font themselves. Students who mentioned headaches, eyestrain, or visual fatigue, acknowledged that they were better equipped to manage this and tended to either rest or use audio technology instead. However, some still reported getting headaches and feeling very tired at the end of the day.

5.4.3 Themes

The overriding theme that was mentioned by all students was an **increase in knowledge** of their VI and the impact it had on their learning. More importantly the confidence and the ability it had given them to advocate for themselves, not just in a school environment. Empowering students with a VI to advocate for themselves is vital for academic success and personal growth. A 10-year literature study investigating enablers and disablers to academic success found that a positive attitude and self-advocacy stood out as key enables to academic success (Simui *et al*., 2018). As students gained a deeper understanding of their VI, they had developed increased confidence and acknowledged they were better equipped to communicate their needs effectively in the classroom. Enhanced knowledge of their VI allowed the students to become stronger self-advocates, which lead to a more supportive learning environment.

"I'm happier asking teachers for help because I can explain better why I need it".
(Year 7 male)

Following the functional vision assessment, students were given comprehensive information about their VI, including a clearer understanding of how it affected their accessibility and learning within the classroom environment. Understanding the specific challenges they faced, and why, fostered a self-awareness and allowed the students to identify and articulate their unique needs in the classroom. With this knowledge they were better able to communicate with teachers, support staff and their peers more confidently, which lead to better collaboration and support. The increased knowledge equipped them with the language and terminology needed to express their requirements more accurately.

“I really like that I now understand why my vision isn’t working and I can explain to other people why I need help.” (Year 7 female)

Knowing more specific detail of their VI instilled a sense of self-confidence in the students –

“I’m not just a vision impaired kid, I can tell people what it means.” (Year 8 male)

This knowledge helped them recognise that their needs within the classroom were valid and that advocating for themselves was essential to achieving their academic goals. As their confidence grows, it is hoped that students will become more proactive in seeking assistance and accommodations where necessary, empowering them to communicate their needs to teachers in a clear and precise manner.

By understanding their VI and advocating for their needs, students can take ownership of their learning experience and become active participants of their educational experience by advocating for modifications that will optimise their learning experience. This sense of ownership can foster a more engaged and motivated approach to learning (McMillan and Hearn, 2008). Developing self-advocacy skills is not limited to the classroom, it equips students with essential life skills for their future. As students become adept at advocating for themselves, they build a foundation for advocating in other aspects of their lives, which may be further education, employment, or social settings.

“I know a lot more about my vision and I like that I can explain to other people about it and the problems that I have.” (Year 8 female)

The feedback from students demonstrated that increased knowledge of their VI had impacted their ability to advocate for themselves in the classroom. With enhanced understanding, the students had gained confidence, increased communications skills, and a sense of ownership over their learning experience. This self-advocacy can foster a supportive and inclusive classroom environment where students with a VI have the potential to thrive academically and personally.

5.4.4 Conclusions

Fully qualitative research was not conducted due to time restraints; however, this limited exploratory research from student feedback provided valuable insights into the benefits of a functional assessment to support a student with a VI and supported the qualitative data obtained.

The informal discussions with students and teachers revealed compelling evidence of the positive impact of functional assessments on the student’s educational experience. Participants reported enhanced self-confidence, increased academic engagement, and improved overall learning outcomes following the implementation of classroom adaptions following the functional assessment.

While the absence of a comprehensive qualitative analysis is acknowledged, these preliminary findings suggest that there is a need for further exploration in this area. Future qualitative investigation may provide a more comprehensive understanding of how functional assessments can be optimally utilised to support students with a VI and contribute to the overall well-being of these students.

CHAPTER 6 : DISCUSSION

Individuals with a VI face unique challenges learning within a classroom environment. The impact of childhood VI can vary significantly with the underlying cause so that each student's needs should be addressed on a case-by-case basis to ensure the individual can work effectively within their specific learning environment.

Two major factors can impact the ability for an individual with a VI to learn optimally within their classroom environment:

1- Accessibility to the curriculum.

2- The ability to work equitably alongside their normally sighted peers.

UNICEF and UNSECO has identified the following key mandates for education:

"All students have the right to a quality education and learning" (UNICEF).

"Inclusion is a process that helps overcome barriers limiting the presence, participation, and achievement of learners. Equity is about ensuring that there is a concern with fairness, such that the education of all learners is seen as having equal importance." (UNESCO 2017).

A 2017 literature review highlighted that accessibility to the curriculum played a pivotal role in the ability for students to achieve their potential at school (Douglas *et al*., 2011). Two approaches were suggested that play a key part in enabling accessibility to material in their preferred format, which could include print size requirements or polarity, and teaching students access skills, including technology. It was noted that although both approaches were important to optimise accessibility, teaching students' accessibility skills has longer term benefits. The gap in reading performance begins to widen at the end of primary school, beginning of high school years (Corn *et al*., 2002; Loh *et al.*, 2024). This thesis has similarly shown that students within South Australia demonstrated the same lag in reading rate, with this gap progressively widening throughout their school years. Therefore, teaching independent access skills at an earlier age to optimise accessibility, particularly in the early years before the transition to high school, could have greater long-term benefits.

While optimising accessibility for students with a VI is essential, it is equally vital to provide them with equitable opportunities to work at the same educational level as their normally sighted peers. Providing a VI individual with the same volume of work as their normally sighted peers when they are only able to read at half the speed does not promote a fair and equitable learning environment. Recognising and accommodating the individual differences in reading speed, visual processing speed and the impact of visual fatigue is imperative for educators to allow the necessary time to complete tasks and assignments without unnecessary pressure. These accommodations should not be centred around providing extra time to complete work and therefore effectively increasing the workloads of these students. Instead, accommodation should include a combination of modification and time requirements. If it takes a student twice as long to complete the same task as their normally sighted peers, an equitable solution would be to reduce this task size so that it takes the same amount of time for them to complete it.

Study objectives and Original Contribution to Knowledge

6.1 Testing the hypothesis that visual function equates to functional vision.

Throughout this thesis, the primary measure of vision function used in the classification of VI - namely VA has been correlated with functional measures of vision performance. This has enabled the development of the theoretical framework to improve the classification of VI based on a more functional overview of the individual's VI rather than a single measure of VA.

When assessing reading performance, in both severe and mild categories of VI the lack of correlation between VA and functional measures of vision implies that it was not possible to determine the optimum print size from VA alone in these categories. In the moderate VI group, although there was a correlation between these measures, the variability was large making it necessary to perform an individual assessment of requirements for each student. The assessment of CPS and RP use similarly required an individualised assessment given there were no correlations between these measures and VA (**Chapters 4.2** and **4.5**).

Feature based visual search RTs did have a positive correlation with VA, with VI individuals with lower VA having significantly slower RTs despite being equally accurate as normally sighted individuals. However, the relationships were more complex and dependant on the number of set sizes, the presence or absence of a target and the age and gender of the VI individual. Notably, although RTs were longer for all students with a VI regardless of these factors, accuracy was the same. This indicated that those with a VI had the same ability to identify the features of the target

- they simply required more time to identify if the target was present or absent amongst the distractors.

The reading reserve also showed a significant correlation, with VI participants with the lowest VA having a reduced reading reserve and were reading closer to their absolute resolution acuity, with 96% of VI students utilising a reading reserve of < 2, which is 50% lower than the value used by individuals with normal vision.

Visual processing measures (TVAS, DEM and Crowding Intensity) demonstrated no correlations with distance VA also. Thus, these functional tests of processing are poorly related to VA and highlight the differences in processing performance that students may have regardless of their VA (**Chapter 4.10).**

One null hypothesis of this thesis was that distance VA was a good predictor of functional vision in VI. The findings presented, reveal a nuanced relationship between VA and functional vision tasks, such as reading performance, visual search times and vision processing. While some correlations were observed in specific subgroups, the overall lack of consistent correlation across different levels of VI highlights some of the limitations of using VA as a standard measure for functional vision. Therefore, this thesis demonstrated that VA is not a sufficient metric to fully represent the complexities of functional vision in VI. Consequently, the findings of this thesis support advocating for a more comprehensive, individualised approach to visual function beyond a standard VA measure.

6.2 Development of an assessment and support framework that represents functional vision

This general discussion examines the elements of functional vision assessments that are required to provide students with a VI optimum accessibility and an equitable environment to learn at the same rate and level as their normally sighted peers.

6.2.1 Reading Analysis

This part of the thesis described in **Chapter 4.2** investigated both the impact of childhood VI on print size requirements, reading speed and polarity of text. Print size requirements were found to be highly variable and had no direct correlation with distance VA measures in participants in the mild or severe VI. A large variation of reading speed was shown across year levels consistent with previous studies (Bosman *et al*., 2006; Corn *et al*., 2002; Douglas *et al*., 2004; Gompel *et al*., 2004; Huurneman *et al*., 2016a; Lovie-Kitchin *et al*., 2001; Lueck *et al*., 2003). Slower reading speeds in children with a VI will hinder their ability to work equitably and efficiently alongside normally sighted children of a similar educational year level. The findings of this thesis, highlight the necessity of determining print size requirements and reading speed for students with a VI on an individual basis so that optimum additional time can be allocated to reading material and thereby providing equitable accommodations for each student based on their functional vision requirements.

Text polarity has been shown in this thesis to also be a key factor in both accessibility and overall reading performance for reading, with some VI participants demonstrating a significant improvement in reading performance with RP text, both in terms of reading speed and font size requirements. VI caused by albinism or retinal dystrophies demonstrated an increased reading speed using RP electronic text. For those with albinism this was presumed to be due to the impact of glare since the same improvement was not demonstrated for these students while using paper-based material. The VI participants with a retinal dystrophy diagnosis were able to read faster and optimise a smaller font size when using RP text, but more studies are required to determine if specific retinal dystrophies were more supported by RP text.

Crowding Intensity

Crowding Intensity relates to the level of visual “crowding” and is defined as the difference in crowded and uncrowded VA. Crowding is a phenomenon in visual perception where nearby objects hinder the accurate recognition or identification of a target object. When a target object, such as a letter or word, is surrounded by elements in close proximity- termed flankers, the visual cortex’s discrimination ability of the target is reduced that influences object perception (Pelli, 2008; Whitney and Levi, 2011). Measuring the Crowding Intensity is one metric that can be used to measure if the effect of crowding elements interferes with target recognition that follows ‘Bouma’s law’, whereby crowding is induced when a flanker is about one half that of the target’s retinal eccentricity (Coates *et al*., 2021).

In the classroom the degree of Crowding Intensity could significantly impact VI individuals to access reading material and contribute to reduced reading speeds, comprehension (He and Legge, 2017), as well as difficulties recognising words and letters (Huurneman *et al.*, 2014). Crowding Intensity also impacts visual search and hinders the ability to locate specific information within text, tables, or graphs, particularly as they become more complex. A higher Crowding Intensity has also been associated in children with abnormal vision processing (van der Zee *et al.*, 2017). Thus, students with a VI with a higher Crowding Intensity are more likely to experience difficulties in the classroom, particularly in terms of reading, making it important to determine the Crowding Intensity for each individual so that adequate letter spacing can be provided if possible **(See Chapter 4.7**).

Reading Reserve

Reading reserve is ratio of the smallest print an individual can just discriminate (reading acuity) to the optimum print size the individual can read comfortable represented by the CPS. Previous findings suggest that for students with a VI the reading reserve is approximately 2.5-7.0 times to enable maximum reading rate (Lovie-Kitchin *et al.*, 2001) and is typically 3 times in normally sighted individuals (Lueck *et al.*, 2003). A reading reserve of 3x would mean that an individual who could just resolve N5 print would have a comfortable reading size font of N15.

This thesis found that in students with a vision impairment in South Australia, reading reserve was significantly lower than this with a range of 1.00-2.69 (mean 1.27) with NP and 1.00-3.85 (mean 1.31) with RP, and 96% of students utilised a reading reserve of <2.0. Using a low RR indicates that students with a VI were reading close to their reading reserve limit during the day which may have a negative impact on their ability to maintain working comfortably and contribute to visual fatigue. For this reason, students with a lower reading reserve may require alternative methods of accessing the curriculum to allow an equitable class environment, such as audio text and/or Braille, and more frequent rests as discussed in **Chapter 4.8**.

Summary

All these factors influence the ability of a student with a VI to access print-based material in a classroom environment and the ability to work equitably alongside their normally sighted peers. Individual assessments of print size requirements, reading speed, polarity, Crowding Intensity and reading reserve are required to determine the individual factors that enable a student with a vision impairment to access class material and work equitably alongside their normally sighted peers.

6.2.2 Visual Perception

The retina receives approximately 100MB of data per second, but only processes 1% of this (Zhaoping, 2019). Visual processing refers to a complex series of tasks that the visual cortex performs to interpret and understand visual information. It requires a series of complex and neural operations that occur in the brain to interpret visual information from the environment. Visual perception is the conscious awareness and understanding of visual stimuli processed by the visual and extrastriate cortex. It is the result of visual processing, where a psychological representation of the visual world is created. Visual perception allows us to recognise objects, scenes, colours, depth and other visual attributes through higher and lower levels of cortical integration of the visual scene over time and space (Kaneoke *et al.*, 2005; Lee *et al*., 2005; Vetter and Newen, 2014).

Bottom-up visual processing refers to the initial stages of information processing within the visual cortex, where information is analysed and combined to form a coherent representation. It involves stages of feature detection, such as shapes, colours and motion; feature integration, which integrates basic information into more complex representations such as contours and textures; object recognition uses information from feature integration to identify objects in the visual field and pattern recognition, where larger patterns or scenes are recognised (Theeuwes, 2010). Bottom-up visual processing is used for quickly detecting visual information in the environment without relying on prior knowledge and is the basis for our ability to perceive the world around us and react to potential threats or opportunities, such as sudden movement in the visual field (Connor *et al*., 2004).

Top-down processing works in conjunction with bottom-up processing, where higher level cognitive processes, such as memory, context, attention, and expectations influence the interpretation of visual information. It uses previous knowledge drawn from experience and memories to analyse the visual scene. Based on this, attention and focus are directed toward salient parts of the visual scene and allows the brain to focus on specific information and discard the less relevant information. To understand visual information that is incomplete or partially obscured it uses context and expectations to interpret information and recognise objects. These expectations and knowledge can influence how we perceive visual information, even if they do not match the sensory input, which can lead to perceptual biases or illusions, where information is interpreted based on pre-existing beliefs or mental models (Gregory, 1997).

Top-down processing is essential for understanding complex visual scenes and can impact perception and understand of the visual world. It works in combination with bottom-up processing, which is the initial analysis of basic visual features to create an understanding of the visual environment (Connor *et al*., 2004; Theeuwes, 2010; Li, 2019).

Visual perception plays a significant role in determining reading ability (Kavale, 1982; Lobier e*t al*., 2013), academic success, (Goldstand *et al*., 2005; Hopkins *et al*., 2019), and can be a contributing factor of visual fatigue (Mizuno *et al*., 2011). Therefore, incorporating visual perception skills into the array of predictive factors can enhance the understanding of what is required access the school curriculum and work alongside normally sighted peers within the classroom.

Studies have also investigated the impact of visual spatial analysis within the classroom environment and found it can impact maintaining the correct place on a page, visual discrimination of similar letters (such as p and q), and the visual fine motor writing of letters and numbers (Kulp and Sortor, 2003). It can also impact the attainment of mathematics ability (Carr *et al*., 2018; Kulp, 1999).

Developmental Eye Movement Test

Although initially designed to study saccadic eye movements, the DEM test has demonstrated a correlation with reading proficiency and visual processing speed (Ayton *et al.*, 2009) and has shown a significant association with academic performance in grade 3 students (Wood *et al.*, 2018). Age-matched reference scores were available for DEM horizontal line reading times (Richman and Garzia, 1990) and were compared with the times obtained for students in both normal and RP printed material as described in **Chapter 4.10.**

A general lag in time to read the numbers on the DEM horizontal card was found for students with VI compared with their aged-match reference times, but most notable was the variability in time difference between students with a VI and reference scores. Mean difference in times to read the horizontal card were 7.5 to 33.9 seconds for NP and ranged from 1.7 to 28.6 seconds with the RP condition. This indicated that, like the results for reading speed on the MNREAD, there was a large variation in times to read the card, corroborating the necessity for the individual assessment of times, comparable to reading speed times.

Test of Visual Analysis Skills

TVAS is a task that investigates visual motor integration – the ability to combine motor skills with the visual information we perceive. It is a vital component of early learning and plays a crucial role in tasks such as writing and drawing within a classroom setting. This task incorporated spatial analysis due to the geometrical shapes involved in the copying task, and VI participants that experienced difficulties with this task may have difficulty within the classroom with tasks such as copying from the board or a book.

In addition to print size requirements and reading speed to determine task time requirements, the thesis has shown that some individuals with a VI were impacted by delays in processing visual information and found it more difficult to process complex visual details. Since the impact of visual analysis skills have their main impact on early learning the test was not designed to assess students beyond grade 3 (Rateau *et al*., 2003). Therefore, since all student participants aged 8 years or older should have been able to complete all the test grids. Of the 53 students that completed the TVAS, only 54.7% completed it accurately. The 24 students that were unable to complete it demonstrated varying performance in visual motor integration. As expected, there was a positive correlation with age as students are known to develop visual motor integration skills with age. **Figure 6.1** illustrates the two distinct groups above and below the trend line with a group of students aged over 8 years not developing these skills with increasing age as discussed in **Chapter 4.10**.

Figure 6.1: Scatter plot of TVAS and age

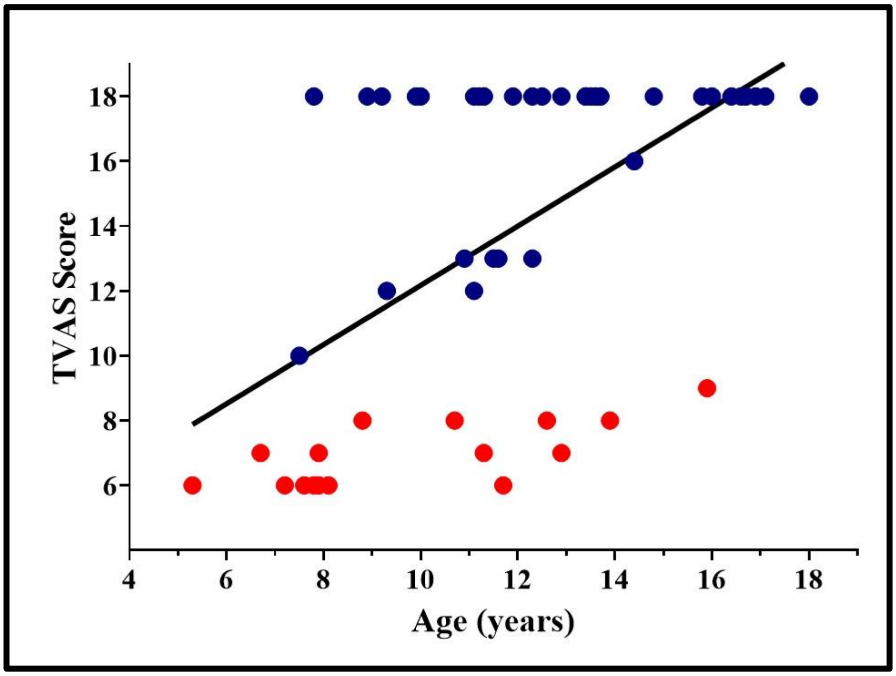


Figure 6.1. Two different trajectories were observed amongst the students. One cluster, indicated by the red circles represents students who did not develop an increase in visual motor skills with age compared to the second cluster (blue circles) that developed full or partial visual motor skills for their age.

6.2.3 Visual Search

Within a classroom environment, scanning plays a large part in the functional vision for a student. Visual search is an important skill that is required to effectively learn in a classroom environment. The ability to pick out relevant information in passages of text, independent research, scanning and picking out important information on graphs, or synthesising information contained within tables. All these abilities are important aspects of visual function and are essential for independent learning for a student with a VI within a classroom. The ability to manage all these tasks are important to independent learning.

Comprehension tasks often require the ability to scan and detect specific pieces of information embedded within text. This process requires skills scanning and visual search capabilities and target distractor similarity can impact the search process in school aged children (Huurneman and Boonstra, 2015). Individuals with a VI have previously demonstrated a weaker search performance than students with normal vision (Tadin *et al*., 2012), which is thought to mainly be due to poor oculomotor control (Huurneman *et al*., 2012). A recent study also showed that amblyopes also demonstrate reduced search performance in the classroom (Black *et al*., 2021).

Feature and conjunctive visual search

Feature search and conjunctive search are two types of visual search tasks used to study how a specific target is located amongst distractors, and the difference between the two is in the nature of the object relative to the distractors (Thornton and Gilden, 2007). A Feature search is a task where the where the distractors differ from the target object by a single distinct feature. The distinguishing feature can be a visual attribute such as colour, orientation or size, and enables quick and efficient location of the target among distractors. A conjunctive search is a search task where the distractors differ from the target object by a combination or conjunction of two or more features. Therefore, no single feature is sufficient to distinguish the target from the distractors. Instead, multiple features must be processed in combination to identify the target, leading to a more complex and time-consuming search process (Duncan and Humphreys, 1989).

Parallel and serial visual processing

Parallel and serial processing refers to the simultaneous and independent analysis of different aspects of visual information across multiple neural pathways (Thornton and Gilden, 2007; Murphy and Greene, 2016).

Parallel vision processing refers to the simultaneous and independent analysis of different aspects of visual information across multiple neural pathways. In this method of processing the visual cortex can process multiple visual features or a scene simultaneously, or in parallel. Each feature, such as colour, shape, motion, and orientation, is processed by specialized neural pathways or modules. It allows for the simultaneous processing of multiple visual features which enables efficient and rapid processing and allows for the extraction of basic visual features in parallel. Parallel search is used in feature search tasks where a single distinctive feature can efficiently identify a target from distractors (Thornton and Gilden, 2007).

Serial vision processing involves the sequential and step-by-step analysis of visual information. Instead of processing all visual features at once, the brain processes the information in a serial manner, one feature or object at a time. This type of processing is more time-consuming and requires attention to each item in a sequence. Serial search is slower and requires more effort compared to parallel processing. It is commonly observed in conjunctive search tasks where multiple features need to be combined to identify a target among distractors.

There is still some debate surrounding the neural architecture of serial and parallel search (Moran *et al*., 2016), with attention (Liu *et al*., 2007), size and salience (Nuthmann *et al*., 2021) with top-down or bottom-up processing streams implicated in search strategies (Patel and Sathian, 2000). How these may differ in a child with a VI will require further examination with the use of eye tracking and imaging to fully elucidate the search strategies employed by those with a VI.

The findings of this thesis indicated slower RTs to a feature based visual search task in participants with VI, with this delay further increasing number of distractors compared to normally sighted individuals (**Chapter 4.6**). These observations agree with those of Huurneman *et al*., (2014), who reported longer search times in students with a VI compared to students with normal vision.

The visual search results provide value insights into the impact of VI on students' visual search abilities. It has significant implications for students as they progress through their academic journey, particularly when they are engaging in independent research, are required to read large amounts of text, search the internet for information or analyse complex graphs or tables. This section of the thesis also revealed a gender difference in visual search that resulted in females requiring a longer search time when a target was absent. This presumed "more cautious" approach, was anecdotally noted by classroom teachers, and provided an interesting insight into the way in which different genders approach a search task and suggests that females may require a longer time when searching for visual information. Despite demonstrating longer search times, this did not affect accuracy (Constable, Loh *et al.,* 2023).

These findings emphasised the importance of providing adequate time for students with a VI to complete classroom tasks and should be considered in combination with other factors such as reading speed time and visual processing time to cater to each individual student to provide optimum accessibility and an equitable working environment.

6.2.4 Nystagmus

Nystagmus can have a notable impact on a student's experience in the classroom and can worsen during tasks that hold greater importance to the student (Tkalcevic and Abel, 2005; Jones *et al*., 2013), which decreases VA. The involuntary eye movements characteristic of nystagmus can lead to challenges in visual tasks, which can significantly affect the student's focus and performance during important learning activities. Poor oculomotor control also affects visual search performance (MacKeben and Fletcher, 2011), which can impact their ability to read and search for information.

Some students with nystagmus may exhibit the "slow to see" phenomenon, which has been investigated in children with infantile nystagmus (Brodsky and Dell’Osso, 2014), by measuring the time it takes to perceive a target (Weaterton *et al*., 2021). This phenomenon is believed to be attributed to the refixation strategies employed by children with infantile nystagmus, involving slow, fast, and catch-up saccades, leading to prolonged target acquisition times (Wang and Dell’Osso, 2007). The "slow to see" effect is related to oculomotor control and the time required to fixate on the object of interest, rather than visual processing time (Dunn *et al*., 2015).

Understanding the "slow to see" phenomenon is necessary in supporting students with nystagmus, especially those with seemingly good visual acuity measures. VA measures are often used for support, but they are not timed tests and do not fully reflect functional abilities in real-world scenarios.

Eighty percent of participants that were included in data analysis in this thesis demonstrated nystagmus in the primary position of gaze (71% male, 91% female). Although the intensity of nystagmus was not recorded for these students, it was important to account for the impact of nystagmus when adapting a student's classroom environment for optimum learning.

When faced with tasks that are perceived as more important, such as examinations, presentations, or assignments, students with nystagmus may experience heightened anxiety and stress. The increased emotional pressure and stress associated with these tasks can potentially exacerbate the nystagmoid eye movements (Cham *et al*., 2008; Jones *et al*., 2013), leading to greater fluctuations in vision and reduced VA. As a result, the student may find it more difficult to read, write, or interpret information accurately, making it challenging for them to demonstrate their true capabilities and knowledge during important periods.

Acknowledging the significant impact that nystagmus can have on a students can help educators and support teachers provide appropriate accommodations and interventions to aid students with nystagmus, both in terms of extra time requirements and volume of work. Providing a supportive and understanding environment can help alleviate the added stress and anxiety the student may face during important tasks through managing their nystagmus (Thurtell, 2015).

6.2.5 Visual fatigue

Visual fatigue (asthenopia) is a significant consideration for a student with a VI within a classroom environment and is not thought to be related to the severity of low vision (Schakel *et al.*, 2019). Feedback from students included in this thesis highlighted that they may experience eye strain and fatigue more rapidly than their normally sighted peers, especially when working extensively on near tasks such as reading.

Visual fatigue can not only affect the overall well-being of students with VI but also impacts their ability to actively participate in the classroom and maintain consistent engagement. Raising awareness of visual fatigue among teachers, support staff, parents, and students helps them understand the potential limitations imposed by the individual's VI, especially during the latter part of the school day and week. Therefore, adopting alternative, non-visual learning methods, such as audio-text and/or Braille, can enhance accessibility and promote a more equitable learning environment for these students.

6.2.6 Knowledge

Increased knowledge appears to be a key aspect of effectively supporting a child with a VI within their educational environment. Previous studies have investigated the impact of well-being of students with a VI in the classroom which can impact self-concept (Datta and Talukdar, 2015) and social inclusion (de Verdier, 2016). Despite the limited feedback obtained, the participants acknowledged the impact that increased knowledge had upon the ability to advocate for themselves and articulate their needs, both to teachers and their peers. When students possess a greater understanding of their unique requirements, it enables them to self-advocate and articulate their needs for appropriate support and accommodations.

For students with a VI that gave feedback in this study, this increased knowledge empowered them to advocate for themselves effectively, which has been shown to be a key enabler to academic success (Simui *et al*., 2018). Armed with a greater understanding of their strengths and challenges, they were better able to articulate their needs to teachers and peers, seeking necessary support. This self-advocacy not only helps them access appropriate accommodations but also builds their self-esteem and confidence in advocating for their rights throughout their educational journey (Cmar and Markoski, 2019).

Enhancing knowledge about the students’ specific challenges, teachers can implement tailored strategies and accommodations that encourage an inclusive learning environment. Additionally, increased awareness among peers can help promote empathy and acceptance, promoting a supportive and welcoming classroom culture.

The transfer of knowledge to parents and teachers is also invaluable in providing optimal support to a student with VI. Continued training of educators and peers on the specific needs of students with VI is essential to promote a supportive learning environment. This includes the provision of ongoing professional development for educators and support staff so they can be informed on best practices for supporting students with VI. The value of training and its impact on the ability for teachers to support students is highlighted in Appendix 6, where statewide support teachers have given feedback on the impact of assessments and how they shaped changes in the approach to supporting students with VI.

6.3 Support

Learning occurs when students are actively involved in the classroom (UNESCO, 2017), and not having work to do within the classroom has a negative impact on students with a VI (Jessup *et al*., 2018).

Supporting a student with a VI through education requires a comprehensive and collaborative effort from educators, support teams, and the broader school community. By addressing their unique needs, providing access to assistive technology, promoting inclusive practices, and fostering a supportive environment, students with a VI can achieve optimum success at school and beyond. Empowering these students to become confident learners and self-advocates ensures they have the tools to thrive academically and socially.

It is also important to recognise that differences in visual abilities do not define a student's intellectual capacity or potential. By providing tailored support, reasonable accommodations, and fostering a growth mindset, educators can empower students with vision impairments to reach their full potential academically and socially. Emphasising their unique strengths and contributions to the learning environment fosters a sense of self-confidence and encourages active participation.

Support should be based around:

- Individualised Education Plans: Developing personalised plans is essential to support students with a vision impairment. These plans should outline specific accommodations, modifications, and goals tailored to the student's unique needs, ensuring that they receive appropriate support in the classroom.

- Access to Assistive Technology: Providing access to assistive technology is vital for students with vision impairments. Screen readers, magnification software, Braille, and other assistive devices enhance their ability to access educational materials and participate actively in class activities. These adaptions should be aimed at teaching a student independent lifelong accessibility skill and consider any changes in vision that may occur in the future due to disease progression.

- Specialised Instruction: Students with vision impairments may require specialised instruction in orientation and mobility, Braille literacy, and daily living skills. Offering these services as part of their education ensures they have the necessary tools to navigate their surroundings independently. Within Australia this takes the form of the Expanded Core

Curriculum (ECC). The ECC was developed to address "the essential learning areas, concepts and experiences that are unique to students with a vision impairment" (Statewide Vision Resource Centre). There are nine areas included in the ECC: Compensatory access, assistive technology, orientation and mobility, career education, independent living, recreation and leisure, sensory efficiency, social skills, self-determination.

• Teacher Training and Professional Development: Educators play a crucial role in supporting students with vision impairments. Teacher qualifications, such as The Qualified Teacher of the Visually Impaired (UK), and Master of Disability Studies: Blindness/Low Vision Specialisation (Australia).

• Collaboration with Support Teams: Collaboration among teachers, parents, special education professionals, and other support personnel is essential. Regular communication and coordination ensure that the student's needs are consistently addressed across all aspects of their education.

• Physical Environment: Creating an inclusive physical environment and ensuring classrooms are well-lit, free from obstacles, and equipped with appropriate seating arrangements supports students with vision impairments in navigating the space safely.

• Self-Advocacy Skills: Encouraging students with vision impairments to develop self-advocacy skills empowers them to communicate their needs effectively and take an active role in their education. Building self-confidence and assertiveness enables them to navigate challenges with resilience.

Supporting a student with a vision impairment through education requires a comprehensive and collaborative effort from educators, support teams, and the broader school community. By addressing their unique needs, providing access to assistive technology, promoting inclusive practices, and fostering a supportive environment, students with VIs can achieve optimum success at school and beyond. Empowering these students to become confident learners and self-advocates ensures they have the tools to thrive academically and socially.

6.4. Independent accessibility for life

When looking at support mechanisms, including type of accessibility and format of preferred learning medium, it is imperative that accommodations go beyond immediate requirements to support students with a VI. By considering changes in vision due to disease progression, accessibility skills can be taught to provide life-long independence. Such skills would not only enable students to navigate their current educational environment effectively but also serve as a foundation for future learning endeavours, such as higher education and career.

Incorporating lifelong independent accessibility skills into accommodations for students with a VI is not only a pedagogical consideration but a fundamental necessity. By recognising the dynamic nature of VI, educational institutions can empower students to navigate transitions effectively, whether to higher education or the workforce. This comprehensive approach aligns with the principles of equality, inclusivity, and lifelong learning, ensuring that individuals with a VI can lead independent and fulfilling lives.

6.4. Summary of Findings

Reading Performance: This chapter has emphasised the significance of understanding a student's reading abilities, including factors such as font size, format and reading speed. Accommodations such as providing materials in large print or using assistive technologies can significantly enhance their reading experience and learning outcomes.

Crowding Intensity: Crowding, a phenomenon where nearby visual elements interfere with object recognition and can impact a student's ability to access the curriculum. Addressing this issue involves using appropriate spacing and formatting techniques to minimise crowding and improve the student's ability to process information.

Reading Reserve: The level of reading reserve a student uses impacts the amount of effort required to read and understand a text. Strategies such as audio support, adaptive reading tools, or adapting workloads can help enable a student to maintain consistent engagement in class through a school day.

Visual Processing: Understanding a student's specific visual processing skills is important to understand the requirements around visual load and time requirements. Tailoring learning methods to accommodate for processing deficits, such as reducing visual detail, can improve their learning experience and retention of information.

Visual Search: Visual search skills are vital for locating relevant information within a text or on a page. Understanding the impact, of a VI has on visual search allows that appropriate adjustments can be made to accessibility formats, workloads and time requirements.

Impact of Nystagmus: Nystagmus can affect reading ability, visual search and contribute to visual fatigue. Educators and support staff need to be aware of the impact and make appropriate adjustments around time requirements, workloads and managing visual fatigue.

Impact of Visual Fatigue: Visual fatigue is common among students with a vision impairment due to the extra effort required for visual tasks. Periodic breaks, alternate formats for learning materials, and adjustments to workloads, including considerations around stressful periods, can reduce visual strain and improve overall engagement.

Enhanced Knowledge of Vision Impairment: Knowledge of their VI and education around why adjustments are required, allows students to understand why they need certain accommodations and are also better at self-advocating for themselves when further support is needed. Enhancing the knowledge of educators and school staff allows them to be more aware of the students challenges and needs and can provide personalised support and accommodations to facilitate learning effectively.

6.5. Limitations

6.5.1 Recruitment

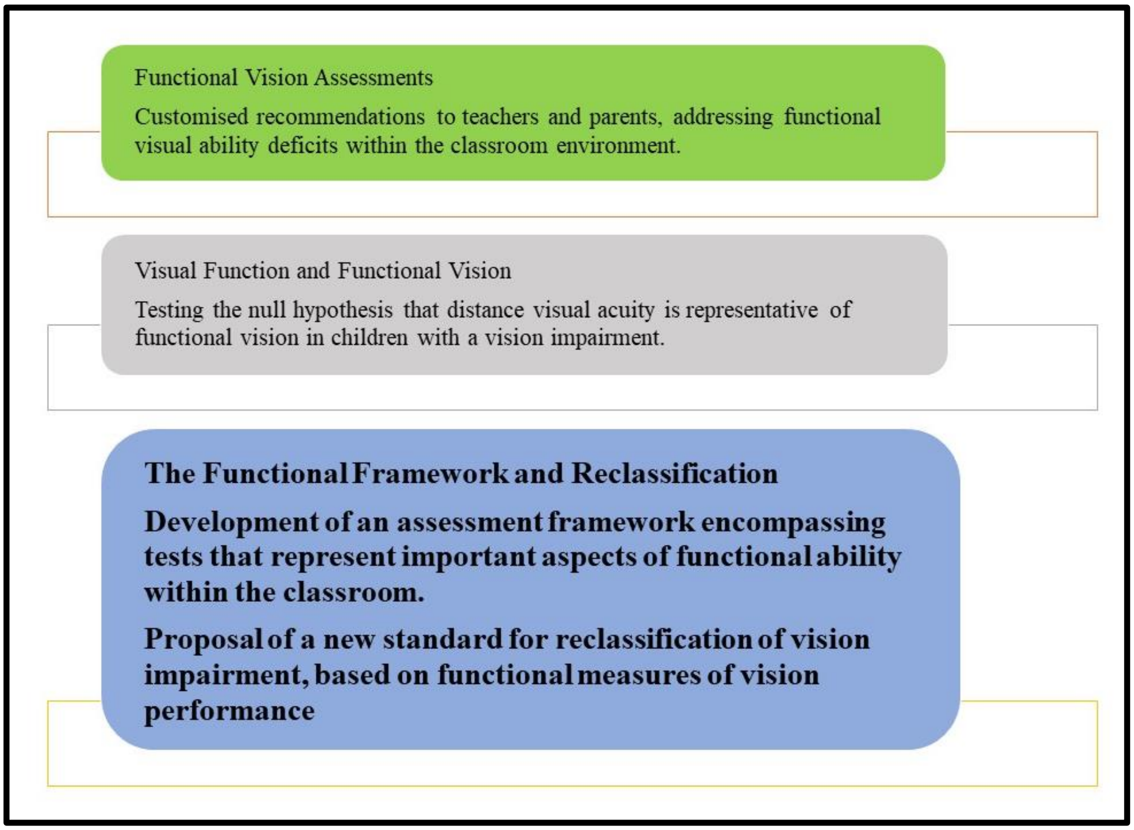
The initial study aimed to recruit approximately 150 students with a VI. This study received ethics approval in April 2020, just after COVID19 was declared a worldwide pandemic. Due to this recruitment was severely hampered. Although South Australia did not experience the same level of lockdown requirements as much of the rest of the country and world, it did impact the ability to access schools. Local education department regulations restricted access to schools, particularly those that included vulnerable populations. Because of this the recruitment number was lower than projected. Further research is required in this area with larger participants, including qualitative research and the impact of the FVA on a student's learning.

6.5.2 Pathology groups

During data analysis, groupings were made based on broad pathological aetiologies. Due to restricted numbers and unavailability of full medical records, this resulted in a generalisation of groups. This was particularly relevant to the retinal dystrophy group that was a heterogenous group of disorders affecting retina and/or cone function which meant that specific associations with the type of retinal dystrophy was not possible. Further work is required in a larger and phenotypically characterised population to fully explore the potential relationships between text polarity, for example, and specific classes of retinal dystrophies with reading performance.

Despite these limitations, the main conclusions of the thesis support a functional assessment of vision for children with a VI to better support their needs within the classroom.

CHAPTER 7 : THE FUNCTIONAL FRAMEWORK



Development of an assessment framework encompassing tests that represent important aspects of functional visual ability within the classroom for children with a vision impairment.

7.1 The Assessment Framework

The proposed assessment framework was developed based on the findings of the thesis outlined in this section with the development of a clinical assessment framework for use by heath care workers and educators to fully support a child with a VI throughout their education.

7.1.1 Reading performance

The first step was to evaluate the reading performance of VI individuals and to then implement appropriate accommodations within the classroom and adjustments to learning materials to optimise classroom performance. The impact on the outcome measure of MRS and its relationship to font size and text polarity should be considered as part of the visual performance assessment.

The measurement of the RR provided guidance as to the likelihood of a student with a VI experiencing visual fatigue during the day. This may prompt additional learning media assessments to determine if an alternative format was required to improve accessibility, such as Braille, particularly if the RR was close to one, i.e., their CPS and reading acuity were similar. Alternatively, audio technology may be required towards the end of the school day to provide a student a respite from visual demands of reading.

7.1.2 Visual Processing

Visual perception is an important aspect in the ability to access the curriculum, including reading ability (Lobier *et al*., 2013), academic success (Hopkins *et al*., 2019), and susceptibility to visual fatigue (Mizuno *et al*., 2011). Understanding visual perception can help in determining a VI student's capacity to fully engage with the school curriculum. Incorporating visual analysis, that includes an element of visual spatial skills, can help provide insight into difficulties within the classroom such as keeping place on a page, distinguishing between similar-looking letters, and fine motor skills required for writing (Kulp and Sortor, 2003). These skills are also important for mathematical abilities (Kulp, 1999). Addressing visual processing difficulties may require simplification of class materials, extra time requirements and alternative learning material to enable optimal accessibility.

7.2.3 Visual Search

The findings of this thesis have indicated that students with a VI exhibit slower visual search times compared to their peers with normal vision, a delay that increases with task complexity, however they were equally accurate. It also revealed a gender difference in visual search times, with females exhibiting what appeared to be a more cautious approach, resulting in longer search times. Adequate time should therefore be allocated for these students to complete tasks to ensure equitable access to learning materials.

7.2.4 Impact of Pathology

The educational settings for students with a VI necessitate accommodations that are sensitive to their specific ocular pathology. Factors such as lighting conditions, contrast sensitivity, and the presence of nystagmus impact the accommodations a student may need to stay engaged in the classroom.

Students with retinal dystrophies and albinism often require a reduction in lighting levels due to photophobia. Minimising sources of glare, including direct glare from class windows, or indirect glare from reflective surfaces, may provide a more comfortable learning environment for these students. Conversely, students with conditions such as ONH or Stargardt's macular dystrophy may require increased lighting to optimise their residual vision and increase task contrast.

Nystagmus can also present additional challenges for a student to be able to work consistently and for extended periods within the classroom. Working rate may be slower due to the "slow to see" phenomenon, where these students take longer to perceive a target due to their poor oculomotor control. The degree of nystagmus may be exacerbated during stressful situations, such as written examinations, resulting in reduced reading efficiency. Nystagmus will also contribute to visual fatigue, affecting sustained attention and potentially overall academic performance. Being aware of these challenges and providing appropriate accommodations, such as extra time, or tasks with a reduced visual load, particularly in stressful situations, will help to support these students.

7.3 A Support Framework

In addition to addressing functional deficits, support should also include accommodations and advice around visual fatigue and building knowledge of VI for student advocacy.

A 2019 systematic review into the association between visual fatigue and VI highlighted that individuals with a VI experience higher levels of visual fatigue than normally sighted individuals that is not associated with their level of vision loss (Schakel *et al*., 2019). Providing frequent breaks and incorporating alternative learning formats can help manage visual fatigue and promote a more comfortable learning experience.

Enhancing knowledge around the limitations in visual ability that are a result of a VI, as well as the interventions needed for classroom support, not only equips teachers to offer better assistance, but also empowers students with insights into their own visual condition and the necessity for accommodations. This, in turn, helps the student become a more effective self-advocate, better equipped to articulate their needs and justify why such accommodations are required.

7.4. Proposed Clinical Guidelines

Clinical guidelines for assessment and support of students with a VI in their educational setting.

Purpose

To provide a framework for educators and support staff to evaluate and accommodate the individual needs of students with VI to ensure equitable access to educational materials and classroom activities.

Scope

These guidelines apply to students with VI in various educational settings who require individual assessment and accommodations to optimise their classroom performance and access to learning materials.

Pre-Assessment Discussions with stakeholders

Students with a VI

- Initiate a conversation with the student in a comfortable setting to discuss any challenges they are experiencing related to their vision.
- Ask open-ended questions about specific issues they may face, such as headaches, eye strain, fatigue, or difficulties with tasks like reading small print or seeing the board.
- Encourage students to share their coping strategies and what modifications they think might help them in the classroom. For example, what lighting they are more comfortable with, or what format do they prefer.

Parents and Teachers of children with a VI

- The assessment should involve open discussions with parents and teachers to gather their observations regarding the student’s classroom experiences and performance.
- Inquire about the student's behaviour that may indicate visual strain, such as headaches, tiredness, eye rubbing, avoidance of visual tasks, or reluctance to participate in activities requiring good VA.
- Request feedback on the student’s interactions with peers and participation in group activities, as these social dynamics can offer insights into their visual capabilities and confidence levels.

Documentation and Considerations

Adding this section ensures that the guidelines advocate for a holistic approach to assessing and accommodating students with VI, recognising the importance of subjective experiences alongside functional vision evaluations.

- Document all reported difficulties and observations to inform the assessment process.
- Consider these subjective accounts alongside functional measures of vision to create a comprehensive profile of the student's current visual function and needs.

7.4.1 Guidelines

Reading Performance Assessment

- Conduct individual assessments to determine each student's font size requirements, maximum reading speed, and optimum text polarity (i.e., black on white or white on black).
- Measure the RR to gauge the potential for visual fatigue. Consider a learning media assessment for alternative formats like Braille and/or audio technology, especially if the RR is close to one.

Crowding Intensity Evaluation

- Measure Crowding Intensity to understand how visual crowding affects a student's ability to recognise characters and words and how this may affect their visual processing time.

- Adjust classroom materials to provide adequate letter spacing and minimise crowding, enhancing readability for students with a VI (ie larger font with larger space between letters and lines).

Reading Reserve Calculation

- Calculate the RR as the ratio of the smallest print size discernible to the comfortable print size for reading.
- Ensure that reading materials are provided in a print size that accommodates the student's RR that is typically 3-4 times their reading acuity (e.g., if the smallest font they can read is 12-point, then print size should be approximately 36-point).

Visual Processing Considerations

- Incorporate visual analysis in assessments to identify issues with visual processing and visual spatial skills that may affect classroom learning, such as keeping place on a page or distinguishing similar-looking letters.

Visual Search Assessment

- Assess visual search times and accuracy, adjusting task times to ensure students with VI have equitable access to educational opportunities.
- Be aware of gender differences in visual search strategies and accommodate accordingly (i.e., females may take longer).

Impact of Pathology on Educational Accommodations

- Tailor accommodations to the student's specific ocular pathology, considering factors such as lighting conditions, contrast sensitivity, and the presence of nystagmus.
- Adjust lighting levels and minimise glare sources for students with photophobia due to their pathological cause of VI such as a retinal dystrophies or albinism.

Nystagmus Management

- Provide additional time and reduce visual load for students with nystagmus, especially during stressful situations such as written examinations.
- Account for the impact of nystagmus on sustained attention and academic performance, offering appropriate accommodations such as additional time.

Addressing Visual Fatigue

- Recognise the signs of visual fatigue in students with VI and implement strategies to mitigate its impact, such as providing non-visual learning methods and frequent breaks to allow some respite.

Promoting Self-Advocacy and Knowledge

- Educate students with VI about their condition to empower self-advocacy.
- Train educators and peers on the specific needs of students with VI to foster an inclusive and supportive learning environment.

Implementation

Independent Accessibility for Life

Future-Oriented Accommodations

- Ensure that accommodations for students with VI consider potential changes in vision, especially due to disease progression.
- Teach accessibility skills that promote lifelong independence, preparing students for effective navigation through their current educational environment and beyond.

Lifelong Accessibility Skills

- Integrate training on the use of access technologies that can aid in learning and daily living.
- Provide resources and instruction on adaptive techniques for accessing information, such as using screen readers, magnification software, and or Braille.
- Educators and support staff should receive training on these guidelines.
- Regularly review and update the accommodations based on the student's changing needs and advancements in educational support for VI.

Monitoring and Evaluation

- Monitor the effectiveness of accommodations through regular feedback from students, educators, and support staff.
- Regularly reassess students' needs to adjust accommodations in response to changes in their visual abilities.

- Collaborate with multidisciplinary teams, including orientation and mobility specialists, to develop comprehensive plans that support transitions to higher education or employment.
- Adjust strategies based on feedback and ongoing assessment of student performance and well-being.
- Encourage students with VI to participate in decision-making processes regarding their accommodations and learning strategies.
- These guidelines should be adapted as needed to fit the specific context of each educational setting and the unique needs of each student with VI. It is essential to maintain a collaborative approach involving educators, support staff, students, and their families to ensure the successful implementation of these accommodations.
- Commit to a philosophy of inclusivity and equality, ensuring that educational practices align with the principles of lifelong learning.
- Provide ongoing professional development for educators and support staff to stay informed on best practices for supporting students with VI.
- Develop individualised transition plans that consider each student's aspirations for higher education or career goals.
- Engage with external agencies and organisations that specialise in supporting individuals with VI to provide a network of support for students as they progress beyond high school as adolescents and enter the workforce as adults.

7.4.2 Clinical Guidelines Flowchart

The clinical guideline flowchart is depicted in **Figure 7.1** and provides steps to fully support a student with VI in their educational journey. From initial dialogue with students, teachers and parents, to the functional assessment framework, addressing functional deficits in the classroom environment that are identified and then monitoring and following up with any interventions to evaluate their impact.

Figure 7.1: Clinical Guidelines Flowchart

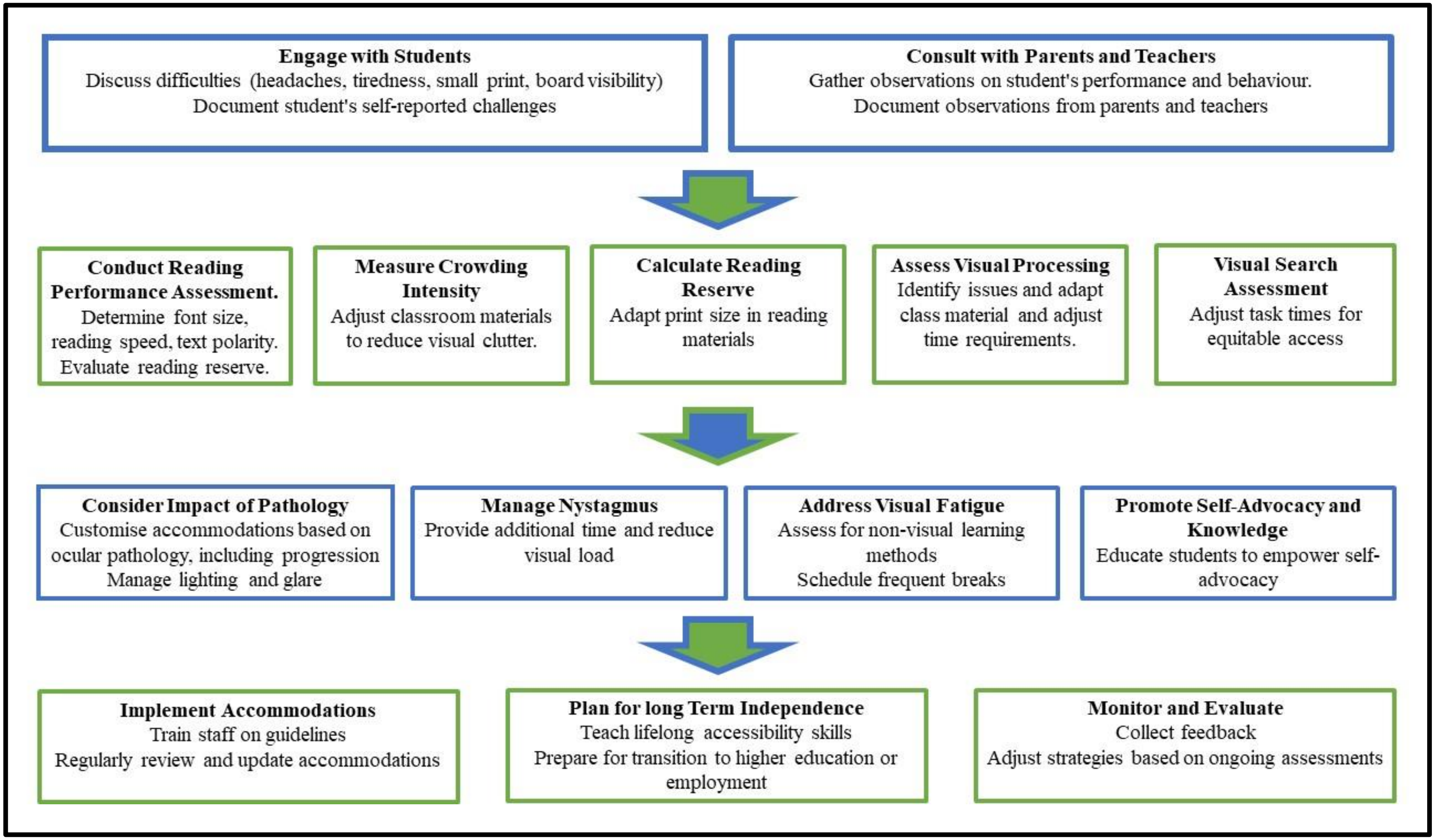


Figure 7.1. Proposed clinical guidelines flowchart detailing the steps involves for educators and support staff to evaluate and accommodate the individual needs of students with VI to ensure equitable access to educational materials and classroom activities. The framework involves communication with the student, parents and teachers, with functional vision assessments followed by implementation of strategies to support the student with a VI and respond to feedback regarding any interventions that may need modifying or adjusting in response to changes in the learning environment and educational demands of the individual student.

7.5. Classification

A proposed revised classification framework shown in **Figure 7.2** encompasses all elements of the functional assessment: reading performance measures, visual processing times, visual search time and accuracy, the impact of pathology and oculomotor control such as nystagmus, with the likely progression. VA is also included as a standard measure of visual function; however, this should also include a measure of Crowding Intensity, and if possible, the time taken to resolve a VA target. The proposed re-classification could be based on the functional impact of VI on educational performance rather than solely on clinical measures of distance high contrast VA and any measurable field defect.

Figure 7.2: A Proposed Classification Framework

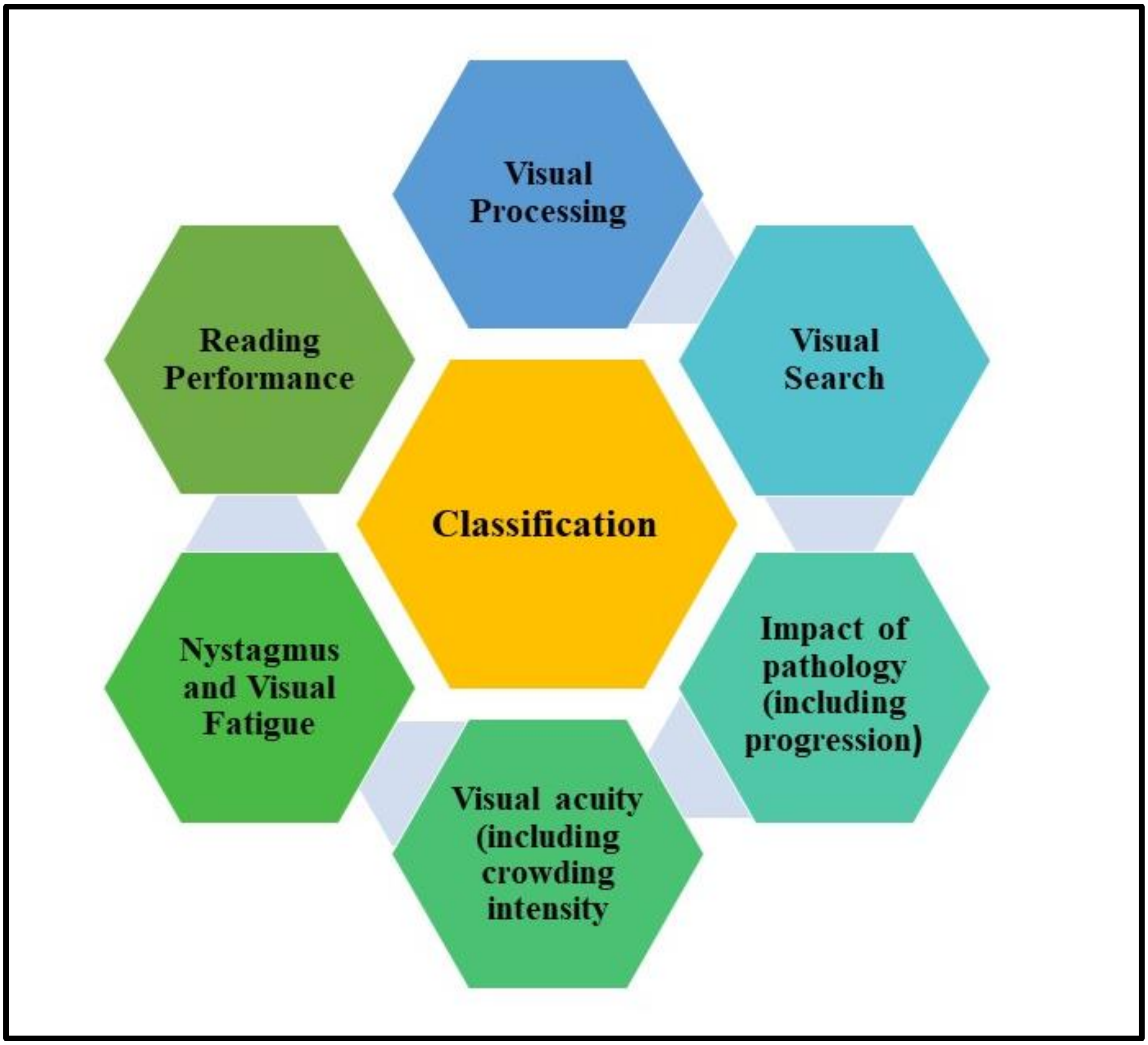
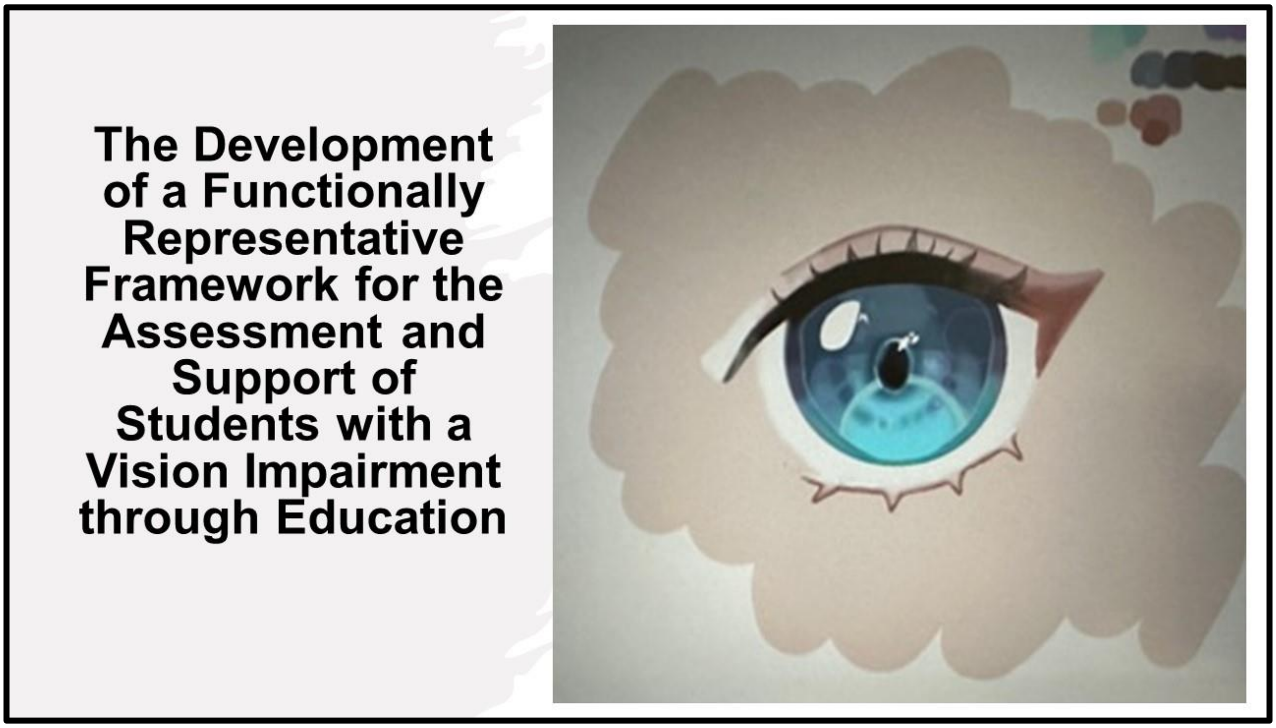


Figure 7.2. Proposed revised classification framework including all elements of the functional vision assessment framework. These include reading performance, visual processing, visual search, impact of pathology (including progression), visual acuity (including Crowding Intensity), nystagmus and visual fatigue.

CHAPTER 8 : CONCLUSIONS



"Every learner matters and matters equally" (UNESCO 2017)

Realising Samuel Genensky's Vision: A Half-Century Later

Reflecting on the advancements in support for students with a VI that has occurred as a result of this thesis, it's impossible not to acknowledge the profound impact of Samuel Genensky's original vision. Born in Massachusetts during the 1930's, Genensky's own journey with VI began under unfortunate circumstances. However, his resilience and ingenuity not only led him to remarkable personal achievements but also laid the groundwork for a more inclusive and understanding approach to VI.

In the 1970’s, Genensky, a visionary in the truest sense, called for a functional classification system for the visually impaired. His goal was ambitious yet simple: to enhance public understanding of the capabilities and needs of individuals with a VI, to improve the quality of services they received, and to empower them towards educational and economic independence. His insights were ahead of their time, particularly his criticism of using VA measured under low luminance as a proxy for visual performance. Genensky, contended correctly that such a narrow measure of vision was inadequate for capturing the real-world functional abilities of individuals with a VI.

After decades of gradual progress in understanding the needs of individuals with a VI, we have finally arrived at a point where Genensky's aspirations are not just ideals but tangible realities. This thesis embodies the essence of his original vision, offering a comprehensive and nuanced approach to assessing and supporting of students with VI. We are now moving beyond the limitations of traditional VA measurements and embracing a more holistic understanding of VI in educational settings.

Moreover, this thesis doesn't just address the immediate educational needs; it looks forward into preparing students with a VI for lifelong learning and independence. This approach aligns with Genensky's vision of empowering individuals with VI to achieve their full potential, both academically and economically by becoming valued members of society and contributing to the artistic, economic and social fabric of society and their communities.

In essence, the journey that began with Samuel Genensky's advocacy over 50 years ago has reached a fulfilling milestone with this thesis. It's a journey that will begin to transform the landscape of support for students with VI within South Australia, turning Genensky's once-distant dream into reality for many.

The findings of this thesis do not support the contention that VA can fully capture the complexities of functional vision in a classroom setting for students with a VI. This thesis provides an original contribution to the field of educational provision for students with a VI by proposing a functional framework that will provide better support to students with a VI during their critical primary and secondary school years.

The framework diverges from traditional methods that primarily focus on VA and visual fields. Instead, it encompasses a more holistic approach by integrating aspects of functional vision assessments such as reading performance, visual search, visual processing, and the impact of pathology, including nystagmus. The support framework goes beyond functional measures to include educational interventions aimed at enhancing the student's knowledge of their VI and its impact and their needs. This would empower students to better understand their unique needs and enable them to advocate for themselves during their educational journey.

One contribution of this research is the proposal of a new classification system. This system is based on functional measures, providing a more nuanced and practical understanding. By moving away from the conventional metrics of VA and visual fields, this classification system offers a more tailored approach to educational support, which would provide more understanding of a student's visual capabilities and limitations within the classroom.

This thesis has diverse and far-reaching implications. For educators and vision specialists, the framework provides a tool for the assessment and support of students with VI. For policymakers, it offers empirical evidence to reconsider and revise existing guidelines and practices. Most importantly, for students with VI, it promises a more inclusive and equitable educational experience.

Changing Polarity

Drawing (reverse polarity on left) and converted to normal polarity (right)

This 12-year-old female year 6 student was not included in the data analysis. English was her second language, so she did not meet the inclusion criteria for reading performance analysis. She was diagnosed with a general "retinal dystrophy", demonstrated a binocular visual acuity of 1.00 logMAR (6/60), reduced contrast sensitivity (0.98 logCS) and poor colour differentiation. Her reading was assessed for classroom support, but she was unable to read any font on the MNREAD in NP due to extreme glare sensitivity. Using RP, she was able to read font 23 at 40cm, with a maximum reading speed of 40 words per minute.

Support in the classroom primarily involved changing all learning material to RP as illustrated in **Figure 8.1**.

Figure 8.1: Learning Material in Reverse Polarity

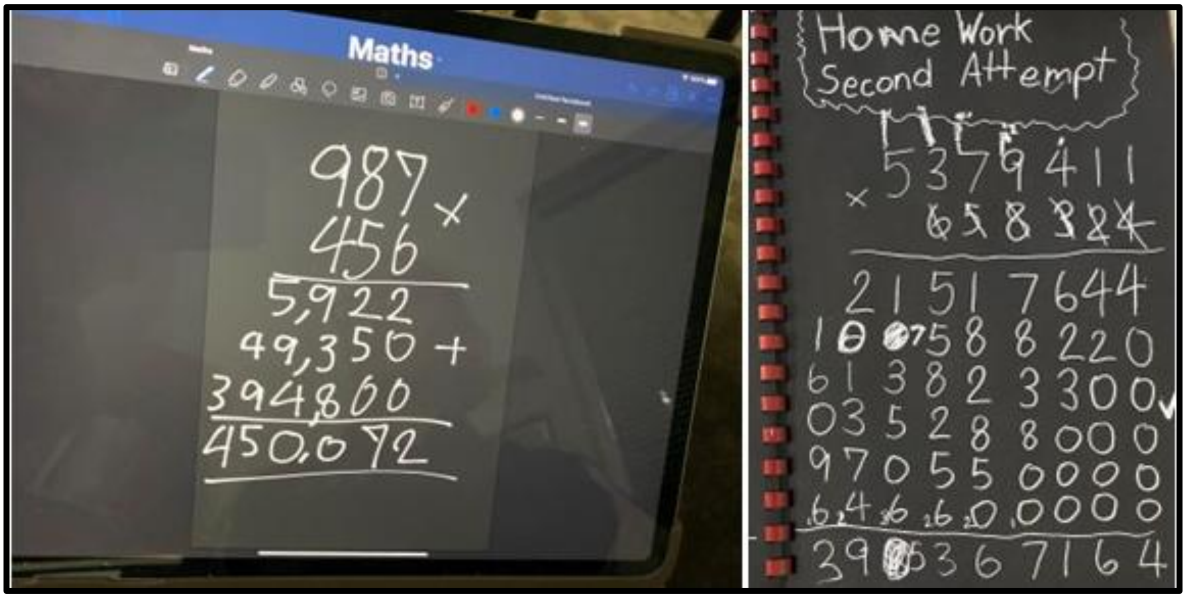


Figure 8.1. An electronic tablet in reverse polarity running a maths program (left) and a handmade book of black paper for use with a white pen (right).

Having learnt to work on a tablet in reverse polarity, she discovered a love of drawing in RP. Being an avid Anime fan, she focussed her drawings on characters she read about in these books. She used online searching to determine the colour she needed to use in reverse polarity, so that when it was viewed in normal polarity by individuals with normal sight, it would be the colours she had read about in her books. She is currently in year 9 in a mainstream high school and in her last report she achieved grades of A or B+.

CHAPTER 9: FUTURE DIRECTIONS

9.1 Cerebral Vision Impairment

Cerebral visual impairment (CVI) refers to a deficiency in visual functioning that arises from damage to the post-chiasmal visual pathways, rather than eye-related conditions. The causes of CVI are diverse and can include hypoxia, traumatic brain injury, cerebral palsy, developmental abnormalities, or infections like meningitis (Ong *et al*., 2023). Essentially, any condition that affects the integrity of the brain's visual processing centres can potentially lead to CVI however, it is commonly attributed to hypoxic-ischemic injury occurring in the period before or shortly after birth (Chhablani and Kekunnaya, 2014).

CVI is now the leading cause of childhood vision impairment in the developed world (Solebo *et al*., 2017). CVI can refer to either cerebral or cortical VI. These terms are often used interchangeably. Cortical refers to damage to the visual pathway after the optic chiasm and can involve damage to the occipital lobe. Cerebral VI refers to damage to the brain involved in higher order visual and sensory processing, thought to be due to dorsal and ventral stream dysfunctions.

CVI is a visual dysfunction caused by anomalies or damage to the visual pathways and structures in the brain. The term is used to describe a wide range of visual impairments that result from injuries or abnormalities in the occipital lobes, or other parts of the brain related to visual processing. Unlike other types of VIs, which are due to problems with the eyes or optic nerve, CVI is specifically related to the processing and interpretation of visual information within the brain.

It is estimated that 30-40% of children with a VI have some degree of CVI and the spectrum of associated disorders can be diverse and include: reduced acuity (87%), reduced contrast sensitivity (48%), strabismus (73%) an abnormal optokinetic response (73%), visual field defects (6%), abnormal motility including difficulty with fixation (48%), smooth pursuits (79%) and saccades (34%) (Fazzi *et al*., 2007).

Characteristics of CVI that students demonstrate can vary widely among individuals but may include: difficulty processing complex detail, light gazing and/ or difficulty engaging with visual stimuli, they can prefer moving rather than static objects, they often prefer familiar rather than novel objects, simple rather than complex objects or scenes, poor social gaze (eye contact), may not be able to integrate two types of sensory information (audio and visual) or may have a delayed visual response (Ong *et al*., 2023).

Although there can be similarities in the presentation of CVI, there currently exists no definitive means to diagnose a child with CVI (McConnell *et al*., 2021). Due to this CVI is often underdiagnosed (Moon *et al*., 2021), resulting in eligibility for provision of support for a student with CVI becoming challenging without the existence of a diagnosis.

9.1.1 Acuity-in-Noise

VA in the presence of luminance noise relates to the disruptive background patterns observed on a Landolt C chart. This disruption is through the random insertion of pixels around the target symbol, the Landolt C, to maintain an equiluminant noise background as shown in **Figure 9.1**.

This manipulation interferes with the spatial frequency of the target optotype. Introducing pixel-based luminance noise into the Landolt C background disrupts initial visual processing in the primary visual cortex. Consequently, the signal-to-noise ratio diminishes, thereby increasing the cognitive load for object identification and challenging the V1 neurons' ability to differentiate objects within a noisy environment. Because of this, children with CVI may experience increased difficulty resolving the Landolt C as the intensity of background pixel noise increases.

Figure 9.1: Acuity-in-Noise

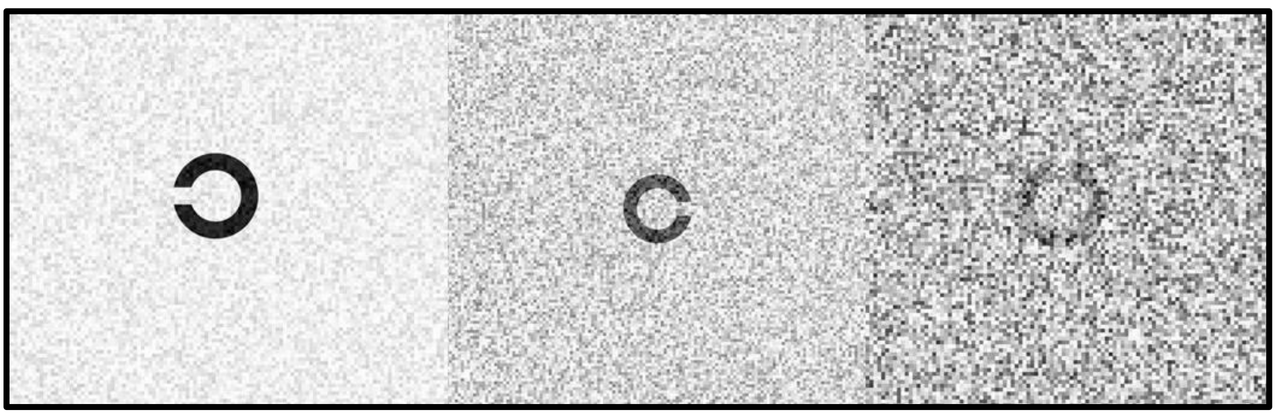


Figure 9.1. Landolt C visual acuity target with increasing background noise. As noise increases the visual acuity decreases and the hypothesis is that the amount of noise will affect acuity in subjects with CVI differently to typical observers.

Acuity-in-noise has been used to explore the impact of acute stroke on functional vision (Wijesundera *et al*., 2020). Stroke can cause difficulty with higher order vision processing, which can be consistent with the pathophysiology of CVI if similar visual processing centres are damaged. Sixty individuals presenting with acute stroke were compared with thirty-seven age-control subjects. The primary outcome of the study focused on acuity-in-noise and revealed that

62% of the participants with acute stroke exhibited decreased acuity-in-noise but had normal high contrast VA. During recovery from the stroke, acuity-in-noise levels also showed recovery.

9.1.2 The development and evaluation of acuity-in-noise as a screening tool for cerebral vision impairment

Acuity-in-noise data will be collected from children with normal vision, children with a VI and children with suspected CVI. VA will be measured at increasing background noise levels as indicated in **Figure 9.2**. Data will then be analysed for a difference in effect of acuity-in-noise in these three sub-groups to determine whether acuity-in-noise could be used as a screening tool for CVI. The recruitment of students will also involve the reassessment of students who participated in this thesis research who have demonstrated reduced vision processing skills or visual motor skills to determine if there are any relationships between these measures.

Figure 9.2: Visual Acuity in Noise

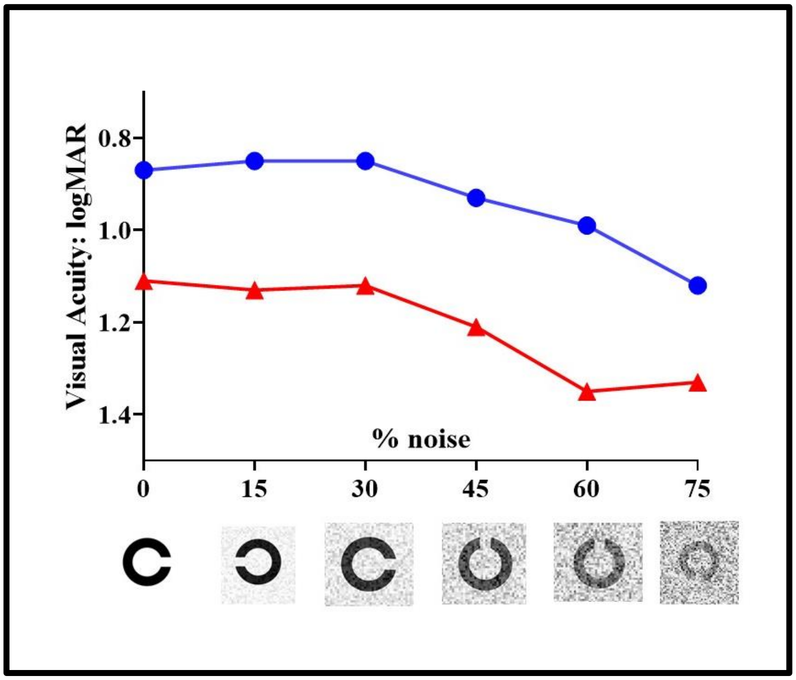


Figure 9.2. Example of the effects of noise on visual acuity measures in two students with a VI and increasing background noise levels of 15, 30, 45, 60 and 75%.

9.2 Reverse Polarity and Retinal Dystrophies

This thesis has highlighted that some students with a VI have a better reading performance when using reverse polarity font. Analysis of the data demonstrated that students with albinism could read faster with RP font on an electronic screen, which may be due to reduced glare, however they required a larger font size to do this. Students with retinal dystrophies were able to read faster with electronic font, paper-based print and required a smaller font size in RP.

One of the limitations of this data is the small groups due to lower-than-expected recruitment numbers because of the COVID19 pandemic at the start of data collection. This led to the grouping of all retinal dystrophies into one pathology group. Additionally, due to inaccessibility of medical records, a definitive diagnosis of the retinal dystrophy phenotype was not available. Retinal dystrophies are a heterogenic group of disorders with varied presentations that can affect vision function. Following on from this thesis, research will be conducted with a paediatric ophthalmologist to investigate the impact of reverse polarity on specific retinal dystrophy types. This is to further investigate why certain students demonstrate an improved reading performance with reverse polarity and whether the benefit of using reverse polarity can be predicted from retinal dystrophy type.

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CONTENTS

CLINICAL AND EXPERIMENTAL OPTOMETRY
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RESEARCH

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Visual acuity and reading print size requirements in children with vision impairment

Lynne Loh, Mallika Prem-Senthil and Paul A Constable

College of Nursing and Health Sciences, Caring Futures Institute, Flinders University, Bedford Park, South Australia, Australia

ABSTRACT

Clinical Relevance: The support of students with a vision impairment throughout education could be enhanced by assessing the functional reading ability of the individual. This visual assessment could inform educators of individualised student needs and potentially improve the academic achievement for these students.

Background: Support for children with a vision impairment within a classroom is typically based on clinical findings of distance visual acuity and visual fields. Therefore, determining optimal print size for reading is essential to ensure best academic outcomes. Secondary aims were to investigate the possible impact of underlying pathology on reading ability.

Methods: Forty-seven participants were recruited from a state-wide support service for children with a vision impairment in South Australia. Three visual acuity groups were formed based on World Health Organisation definitions of mild, moderate, and severe vision impairment. Correlation between clinical measures of distance visual acuity using the Freiburg Visual Acuity Test, were compared with reading acuity and critical print size (smallest font before reading speed reduced) using Minnesota low vision reading chart (MNREAD).

Results: No significant correlations were found for mild (0.20–0.49 logMAR) and severe (1.00–1.52 logMAR) vision impairment groups between distance visual acuity and reading acuity read ($p = .64$, CI [−.585, .395]/$p = .82$, CI [−.48, .58]) or critical print size ($p = .78$, CI [−.57, .45]/$p = .43$, CI [−.34, .68]). A significant correlation was found for the moderate vision impairment group: 0.50–0.99 logMAR for minimum reading acuity ($p < .001$, CI [.44, .91]) and critical print size ($p = .03$, CI [.05, .80]).

Conclusions: Standard clinical measures of distance visual acuity are an unpredictable estimate of reading ability in children with mild and severe vision impairment. Additional measures of functional near reading ability could provide a more meaningful indicator of reading ability and help provide optimum support to students through education.

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Introduction

Blindness and vision impairment can significantly impact the social development of a child, academic achievement, and self-esteem, particularly in an educational environment.[1] The global prevalence of childhood vision impairment is estimated to be 19 million, with a high proportion (31%) due to inherited retinal conditions.[2–4] The main causes of childhood vision impairment in developed countries are cerebral vision impairment, optic nerve anomalies, albinism, and inherited retinal dystrophies.[2–9]

Vision impairment is typically based upon the World Health Organization (WHO) definitions, with visual acuity 6/12 to 6/18 (0.30–0.50 logMAR) defined as mild impairment, 6/18 to 6/60 (0.50–1.00 logMAR), moderate impairment and 6/60 to 3/60 (1.00–1.30 logMAR) as severe. Blindness is defined as presenting visual acuity less than 3/60.[10] Vision below the level of 1.00 logMAR (6/60 or worse) is considered legally blind in many countries and qualifies the individual to register for support, which currently includes the Blind Pension (Australia), Federal and State Benefits (USA) or Disability Living Allowance (UK).

Support for children with a vision impairment, within the classroom environment, is typically based upon clinical measures of high contrast distance visual acuity and, where possible, a visual field assessment. The assumption being that, as with normally functioning eyes, distance visual acuity correlates with near visual acuity and subsequently readable font size. Consideration of additional factors that can impact a paediatric vision assessment include testing methods, environmental conditions, oculomotor control, visual field size and childhood behaviours, which may impact distance acuity measures.[11–13] Reduced contrast sensitivity may also reduce reading speed, especially if the print quality is poor.[14] Outside of a clinical study setting, such as in the classroom, consideration of these factors may not be applied consistently and reduce the ability for a child to access learning materials.

Near acuity is defined as the reading acuity that can be read at the habitual reading distance. Typically, distance and near acuity are related so that a distance visual acuity 0.00 logMAR corresponds to a near reading font size of 3.7-point print at 40 cm. However, it is also important to consider optimum font size that can be read comfortably, without reducing reading speed or causing excessive strain, to ensure that students with a vision impairment can sustain reading throughout the course of the school day.

Reading and literacy skills have been shown to be a good indicator of future academic performance,[15,16] and most

CONTACT Lynne Loh lynne.loh@flinders.edu.au
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learning time within a classroom is based around near vision tasks, predominantly allocated to reading and writing.[17] Previous studies have highlighted the impact of childhood vision impairment on reading speed, with the consensus of findings demonstrating a slower reading speed in children with a vision impairment compared with age matched normally sighted children.[18–24] Studies have also investigated the difference in reading characteristics between children with a vision impairment and their normally sighted peers, including the role of phonology and reading comprehension. These studies found that children with a vision impairment employ the same reading strategies and have the same comprehension ability – but are only limited by the speed at which they read.[18,19,23,24]

Previous research has also indicated an association between low vision and reduced academic performance, based on classroom grades and national testing results.[25,26] Therefore, determining the optimum print size for an individual with a vision impairment, that can be read at maximum speed, is critical to their ability to engage effectively within the classroom learning environment and achieve their full academic potential.

Font size and reading speed are intrinsically linked; if font size is too large, then reading speed is slower due to a reduced number of words on a page and the individual is required to scan more.[27] As large font size is reduced, reading speed increases until the maximum reading speed is achieved, where it stays relatively constant across several font sizes. As resolutions limits are neared, the reading speed slope drops sharply until resolution limits are reached and the individual is unable to resolve the smaller font to continue reading. Critical print size is used to determine the font size for a child with a vision impairment to use within the classroom to achieve optimum reading performance.

The main aim of this study was to evaluate the relationship between distance visual acuity and print size reading ability in children with a vision impairment. Secondary aims were to investigate the possible impact of underlying pathology on reading ability.

Methods

Participants

Seventy children were recruited from a state-wide support service for children with a vision impairment South Australia. All children had previously been diagnosed, by an ophthalmologist, with a pathological vision impairment. Eligible children, in full time education, were identified by specialist low vision trained state-wide support teachers in South Australia. Since the Minnesota low vision reading chart (MNREAD) uses vocabulary from high frequency words used in reading material of 8-year-old children, students were only included if their teacher reported a reading age of eight years and above.

Children were excluded ($n = 23$) if they had a diagnosis of dyslexia, language or communication disorder, intellectual disability (IQ < 75) or were unable to read the largest font sentences on the MNREAD chart at 10 cm.

Distance visual acuity

Habitual refraction was worn for distance and reading analysis as required. Binocular distance visual acuity was measured using the Freiburg Visual Acuity Test (FrACT).[28] FrACT uses a four-alternative forced-choice paradigm using Landolt rings making it suitable for young children and can quantify vision at the lower end of the visual acuity range which has traditionally been given a semi-quantitative value (i.e. hand movements or count fingers).[29] There is also no clinically significant difference between visual acuity measures using FrACT Landolt C and ETDRS charts.[30]

Visual acuity groups

Based on the level of binocular distance visual acuity, participants were grouped into three levels for analysis. The visual acuity groups were defined based on the definitions of mild, moderate, and severe vision impairment by the WHO.[10] Group-severe: 1.00–1.52 logMAR (6/60–6/190), group-moderate: 0.50–0.99 logMAR (6/19–6/60), and group-mild:0.20–0.49 (6/9–6/18).

The forty-seven eligible participants (28 male and 19 female) with age (mean ± SD) 12.2 ± 3.0 (range 5.0–18.0) and school grade 6.3 ± 3.1 (Reception to grade 12) underwent clinical measures of distance visual acuity and full reading analysis. Pathological causes of vision impairment were predominantly inherited retinal dystrophies (34%) or albinism (28%) optic nerve disorders, including optic nerve hypoplasia, optic nerve glioma and optic neuropathy accounted for 15% of participants. Two participants had retinopathy of prematurity and one each had aniridia, iris/choroid coloboma, uveitis, retinal detachment, congenital glaucoma and congenital cataracts. Idiopathic infantile nystagmus was present in three participants, with overall presence of nystagmus secondary to primary pathology in 83% of the participants (see Figure 1). There were no significant differences ($p > .08$) between groups for sex, age, academic year, or nystagmus present (See Table 1). An analysis of pathology by each visual acuity group is included in supplementary material.

Reading performance

Reading analysis was performed using the MNREAD[31] on an iPad7, iOS version 14.4.1. MNREAD was used to assess reading acuity read (the smallest print size that can be read without significant errors) and critical print size (the smallest font size read at maximum reading speed).[32] The iPad was mounted in landscape mode and the reading distance constantly monitored by a fixed ruler. Reading distance was fixed at 40 cm unless the student was unable to read the largest font at this distance, whereby the reading distance was halved. Sentence presentation was initiated and stopped by the examiner to control the accuracy of timing. Reading tests were performed with different sentence sets to avoid memorisation and an average of results taken. Room illumination was kept at a constant classroom level of between 450–500 Lux.

For comfortable, sustained reading performance, the measurement of reading acuity is not as important as the critical print size,[20,27,33] which is the smallest font size before reading speed begins to decrease. It is defined as the print size at which subsequent smaller print sizes were read at 1.96 standard deviations slower than the mean of the preceding print sizes.[31] For further details on the MNREAD, see supplementary material.

Statistics

Relationships between distance visual acuity and reading performance (reading acuity and critical print size) were evaluated using Pearson's correlation coefficient. All analyses

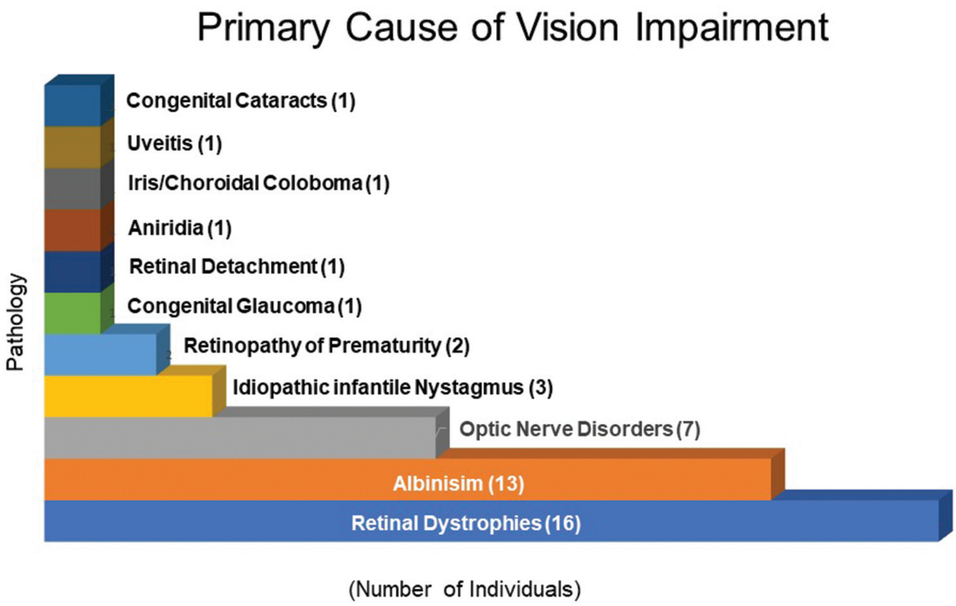

Figure 1. Distribution of the primary cause of vision impairment in the study population with the majority being due to either an inherited retinal dystrophy or albinism.

Table 1. Characteristics of the vision impairment study population by visual acuity group. All values are mean ± SD. CS Contrast Sensitivity, *M* = male, F = female.

	All ($n = 47$)	Group-severe ($n = 16$)	Group-moderate ($n = 17$)	Group-mild ($n = 14$)	*p*
Sex (M:F)	28:19	12:4	11:6	5:9	.08
Age (years)	12.2 ± 3.0	12.5 ± 2.9	11.9 ± 3.0	12.5 ± 3.2	.97
Academic Year	6.3 ± 3.1	6.7 ± 2.9	6.0 ± 3.3	6.4 ± 3.2	.42
Nystagmus Present %	83	70	94	86	.15
Log CS Threshold	1.25 ± 0.45	1.02 ± 0.36	1.21 ± 0.41	1.56 ± .43	.006

were performed using IBM SPSS version 28. A *p*-value of < .05 was taken as significant. Non-parametric tests (Chi-Squared Test of Independence, Kruskal-Wallis Test) were used as appropriate to compare parameters between the three acuity groups. All values are reported as mean ± standard deviation (SD) unless otherwise specified.

Ethical approval

This study was approved by the Women's and Children's Health Network, Human Research Ethics Committee, South Australia, and the South Australian Department of Education. All children and parents gave informed written informed consent prior to participation.

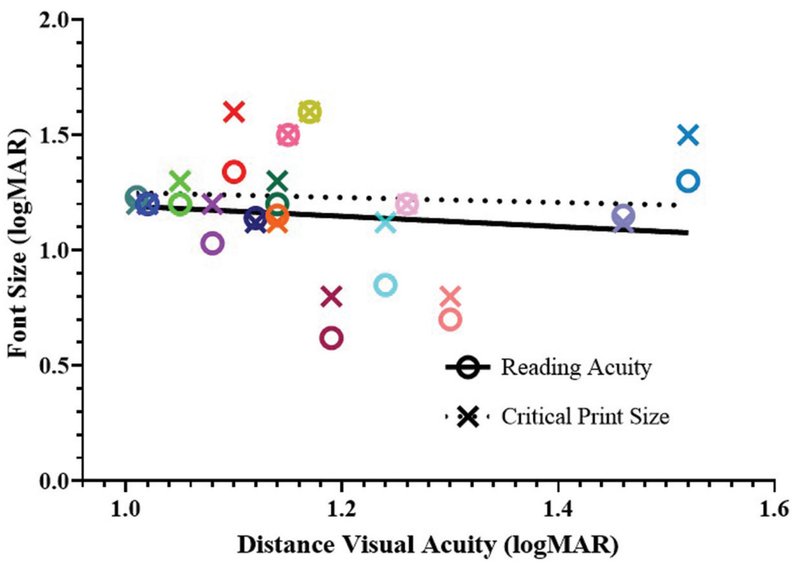

Figure 2. Relationship between reading acuity (circles), critical print size (crosses) and distance visual acuity for $n = 16$ subjects in group-severe. Each colour represents an individual subject. No significant correlations were found in the acuity range 0.20–0.49 LogMAR for minimum reading acuity ($p < .82$) or critical print size ($p < .43$). With regression lines for reading acuity (solid line) and critical print size (dotted line).

Results

Distance visual acuity and reading performance

Group-severe participants demonstrated no significant correlation between binocular distance visual acuity and reading acuity (p = .64, r^2 = 02, CI [–.59, .40]) or critical print size (p = .78, r^2 = .006, CI [–.57, .45]) (Figure 2). The participants within group-mild, with the highest level of visual acuity, also demonstrated no significant correlation between distance visual acuity and reading acuity (p = .82, r^2 = .005, CI [–.48, .58]) or critical print size (p = .43, r^2 = .05, CI [–.34, .68]) (Figure 4).

Participants in group-moderate demonstrated a significant correlation of distance visual acuity to reading acuity ($p < .001$, r^2 = .58, CI [.44, .91]) and critical print size (p = .03, r^2 = .27, CI [.05, .80]). See Figure 3 and Table 2. Significant correlations were demonstrated between reading acuity and critical print size in group-severe and group-moderate ($p < .001$/p = .04). There was non-correlation between reading acuity and critical print size in group-mild (p = .06).

Pathology and reading performance

The relationship between distance visual acuity and reading prints size requirements was analysed based on pathology (see Table 3). There was a significant correlation between visual acuity and reading acuity and critical print size in the students with retinal dystrophies ($p < .001$) and optic nerve disorders (p = .05/p = .01).

Within visual acuity groups, group-moderate (n = 17), which was comprised predominantly of individuals with an inherited retinal dystrophy (n = 10), there was a significant correlation between distance visual acuity and reading acuity (p = .008, r^2 = .61, CI [.30, .95]) but not critical print size

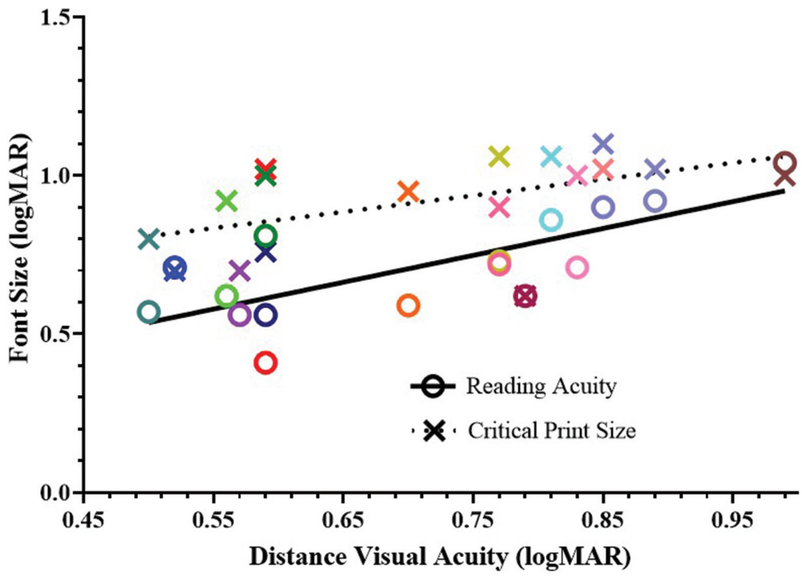

Figure 3. Relationship between reading acuity (circles), critical print size (crosses) and distance visual acuity for n = 17 subjects in Group-moderate. Each colour represents an individual subject. Significant correlations were found in the acuity range 0.50-0.99 logMAR for minimum reading acuity ($p < .001$) or critical print size ($p < .03$). With regression lines for reading acuity (solid line) and critical print size (dotted line).

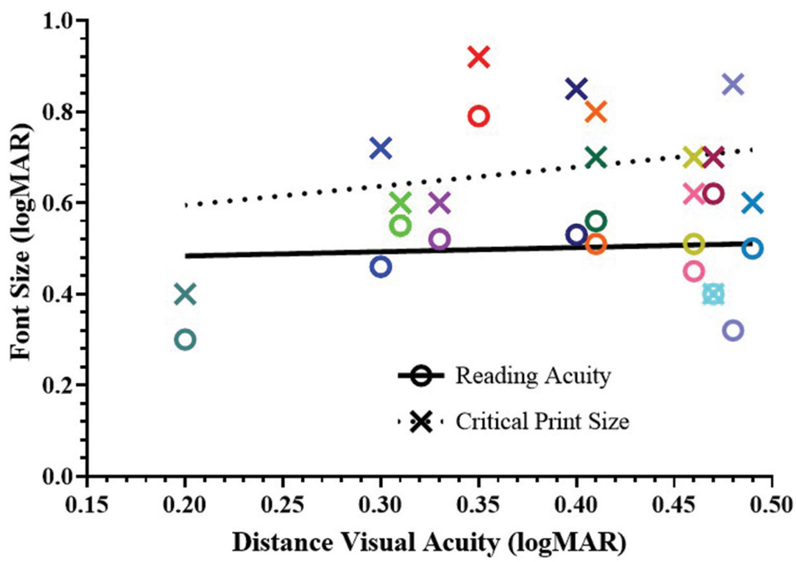

Figure 4. Relationship between reading acuity (circles), critical print size (crosses) and distance visual acuity for n = 14 subjects in Group-mild. Each colour represents an individual subject. No significant correlations were found in the acuity range 0.20-0.49 LogMAR for minimum reading acuity (p = .82) or critical print size (p = .43). With regression lines for reading acuity (solid line) and critical print size (dotted line).

Table 2. Correlation coefficients and significance levels for distance and near measures of acuity and reading. Significant correlations between distance visual acuity and reading performance for group-moderate (moderate vision impairment) only.

	Group-severe	Group-moderate	Group-mild
Distance Visual Acuity and Reading Acuity	$r^2 = .02$ $p = .64$	$r^2 = .58$ $p < .001$	$r^2 = .006$ $p = .82$
Distance Visual Acuity and Critical Print Size	$r^2 = .006$ $p = .78$	$r^2 = .27$ $p = .03$	$r^2 = .05$ $p = .43$

Table 3. Correlation coefficients and significance levels for distance and near measures of acuity and reading based on pathology. Significant correlations between distance visual acuity and reading performance for optic nerve disorders and retinal dystrophies.

	Optic Nerve disorders ($n = 7$)	Albinism ($n = 13$)	Retinal Dystrophies ($n = 16$)
Distance Visual Acuity and Reading Acuity	$r^2 = .58$ $p = .05$	$r^2 = .01$ $p = .50$	$r^2 = .86$ $p < .001$
Distance Visual Acuity and Critical Print Size	$r^2 = .45$ $p = .01$	$r^2 = .21$ $p = .11$	$r^2 = .65$ $p < .001$

($p = .07$, $r^2 = .35$, CI [−.07, .89]) of the individuals with an inherited retinal dystrophy.

In contrast, for group-mild ($n = 14$), which was comprised predominantly of individuals with albinism ($n = 9$), there were no significant correlations between distance visual acuity and reading acuity ($p = .84$, $r^2 = .006$, CI [−.71, .62]) or critical print size ($p = .99$, $r^2 < .001$, CI [−.67, .67]) of individuals with albinism. Group-severe contained a large variation of pathologies and so no direct comparisons could be made between acuity measures and the main pathology.

Discussion

The main findings of this study were no significant correlations between binocular distance visual acuity and reading acuity or critical print size ($p > .47$) for children whose vision impairment is classified as being mild or severe. Therefore, distance visual acuity is not a good predictor of reading ability for children whose distance acuity lies between the ranges of 1.00–1.52 logMAR (group-severe) and 0.20–0.49 logMAR (group-mild). Within group-severe, a non-significant relationship was not unexpected given the lower levels of distance visual acuity for this group. For these individuals, it is important to evaluate their reading font size to determine the optimum accessibility materials for learning. While some of these participants can adequately access print materials in enlarged format, this study indicated that due to the variation in print sizes that are read, some students with similar visual acuities may require a larger font size and therefore a more efficient way to access learning materials in the classroom.

For group-mild individuals, the findings also support a lack of correlation between distance acuity and reading performance and may also require the reading performance measures to be used as a more reliable indicator of classroom performance for reading tasks, despite their 'relatively' good distance acuity.

In contrast, group-moderate participants, with moderate vision impairment, did show a significant correlation between binocular distance visual acuity measures and font size requirements for reading (critical print size $p = .03$ and reading acuity $p < .001$). The reasons for this are uncertain given that between the groups there was no significant differences in nystagmus, age, sex, or academic year levels.

One possible explanation may be that in the group with moderate vision impairment, the participants still maintained adequate oculomotor control and functional visual field, so that distance and near acuity measures were still correlated. These findings suggest that the underlying pathology may be an important factor that influences reading performance, and that reading performance may be more related to the extent of oculomotor control (nystagmus), the functional field of vision, room luminance and the amount of glare. For example, the group with mild vision impairment was dominated by children with albinism (63%) compared to group with a severe (13%) and moderate (18%) vision impairment, whose visual performance would be more likely to be affected by glare and their oculomotor control.

Previous studies have shown that albinism is a contributing factor in decreased reading performance and is thought to be due to nystagmus and foveal hypoplasia with consequent reductions in oculomotor control and susceptibility to glare.[34,35] Although there were no significant group differences between children with and without nystagmus, the severity of the nystagmus was not assessed and may have increased with high room luminance and/or stress during testing,[36] thus negatively impacting reading performance.

Variations observed between groups therefore may be due to interactions of additional factors that can affect reading ability, such as convergence ability, crowding intensity, scanning ability, contrast sensitivity and the extent of the functional field of vision that have all been implicated in reading ability.[21,37,38] These findings suggest that a single measure of distance or near acuity cannot accurately predict the reading performance of every individual child and therefore an assessment of functional reading ability should be a part of the clinical assessment for children with a vision impairment. This would help guide educators to ensure the optimal print size was used to maximise reading speed without a loss of comprehension.

Previous studies have found that reading speed is slower in children with a vision impairment[18–24]; however, this study has also demonstrated that font size requirements are variable and cannot be predicted from standard measures of distance acuity. It highlights the importance of determining critical print size for these individuals, which is the optimal font size that can be read at maximum reading speed. Lighting and glare levels also play a large factor in visual performance, particularly in people with low vision, and a recent case report has highlighted that for a child with a cone dystrophy, reading speed can be improved by reversing the polarity to white text on a black background on electronic displays.[39]

The visual performance of a student in a classroom may be dramatically changed by lighting levels, which can reduce the symptoms of visual fatigue.[40] A student with cone dystrophy or albinism may be negatively impacted by a bright well-lit classroom, as opposed to a student with optic nerve hypoplasia who may need extra light to help differentiate detail. This difference in visual ability, dependent on pathology, may have contributed to the variation in reading results obtained within the groups – as luminance levels can impact reading ability and should also be considered when determining the optimal conditions for a student to read in the classroom.

Therefore, to better classify children according to their vision impairment it is recommended that several factors be considered when evaluating students for support within a classroom, such as their underlying pathology, luminance, contrast of the text, their functional visual field and ocular motor control. By adopting an integrated approach, children with a vision impairment would be better supported in the classroom by ensuring font was at least as large as the critical print size. Contrast (polarity) and room luminance should be optimal, so that visual fatigue and an inability to engage with learning materials appropriately is avoided.

Visual fatigue can be a significant issue for students with low vision, particularly at the end of a school day, which can impact self-esteem and quality of life.[1,40] Strategies that may help to reduce the impact of visual fatigue, such as increasing working distance, regular breaks from visually demanding tasks, encouraging an increase in outdoor play and the use of adaptive technology, may help the child perform more comfortably within the classroom. The use of relaxation techniques to cope with visual fatigue, such a listening to music and napping, may also provide additional methods to support these children.[40] The use of electronic devices that can easily enlarge font to a comfortable size and change contrast or reverse the polarity of text to white on black, can help to improve accessibility to reading materials.

These findings have highlighted that distance visual acuity does not always correlate with the optimal print size requirements and depends upon, in part, the cause of the underlying vision impairment. Thus, the standard clinical measure of distance visual acuity may not always be adequate to determine the font size requirements for children with a vision impairment. Additional measures of near reading ability could assist educators to provide appropriate modifications to text size and contrast to fully support the child.

Considering the range of other factors that affect reading performance, such as pathology, contrast sensitivity, crowding intensity, scanning ability, impact of lighting levels and the presence of nystagmus, is important to optimise environmental conditions so that a student can work in a classroom at their optimum capacity. Further work will be needed to determine whether educational outcomes can be improved by adopting a more individual and holistic approach to assess reading performance in children with vision impairment. Investigating print size requirements in adults with a vision impairment resulting from glaucoma or macular degeneration would also be beneficial to help adults optimise their work productivity and improve their quality of life.

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ORCID

Lynne Loh http://orcid.org/0000-0002-1357-9395
Mallika Prem-Senthil http://orcid.org/0000-0001-6560-5594
Paul A Constable http://orcid.org/0000-0002-3994-1700

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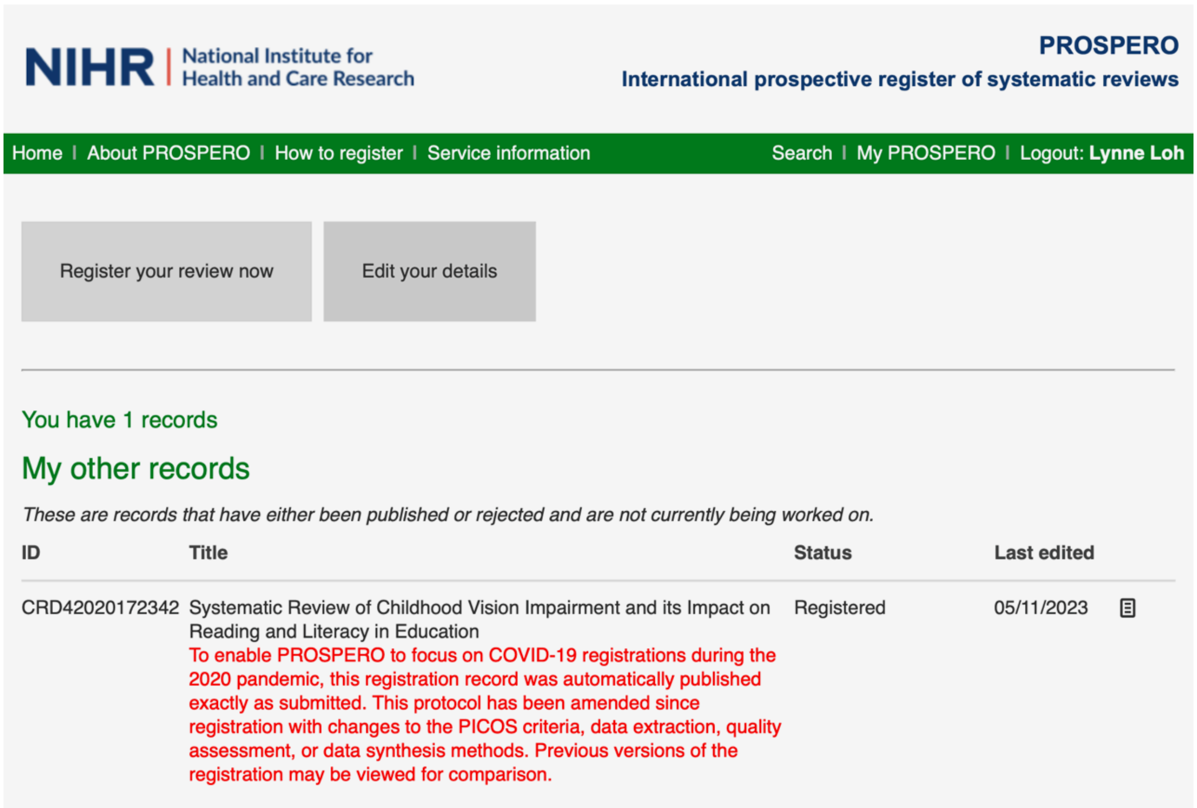
A systematic review of the impact of childhood vision impairment on reading and literacy in education

Prospero



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CRD42020172342	Systematic Review of Childhood Vision Impairment and its Impact on Reading and Literacy in Education To enable PROSPERO to focus on COVID-19 registrations during the 2020 pandemic, this registration record was automatically published exactly as submitted. This protocol has been amended since registration with changes to the PICOS criteria, data extraction, quality assessment, or data synthesis methods. Previous versions of the registration may be viewed for comparison.	Registered	05/11/2023

Search Strategy

Search: Including MeSH (Medical Subject Headings); terms for population

(Child* or Adolescent or youth or "young people").mp.

adolescent/ or child/ or child, preschool/

1 or 2.

(Vision impaired or blind*).mp.

(Visual* adj2 (acuity or performance or impaired)).mp.

vision disorders/ or blindness/ or vision, low/

4 or 5 or 6

Search: Including MeSH terms for outcomes

((performance or impact or improv* or success) adj3 (education or school* or classroom or academic or literacy or reading or writing)).mp.

3 and 7 and 8

{“education performance” or “school performance” or “classroom performance” or “academic performance”

“education* impact” or ‘school impact” or “classroom impact” or “academic impact”

“education* improvement” or ‘school improvement” or “classroom improvement” or “academic improvement”

“education* success” or ‘school success” or “classroom success” or “academic success”}

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REVIEW

A systematic review of the impact of childhood vision impairment on reading and literacy in education

Lynne Loh*, Mallika Prem-Senthil, Paul A. Constable

College of Nursing and Health Sciences, Caring Futures Institute, Flinders University, Adelaide, Australia

KEYWORDS
Child;
Vision impairment;
Blindness;
Education;
Literacy;
Reading

Abstract
Purpose: This systematic review evaluates current literature on the impact vision impairment has on reading and literacy levels within education.
Methods: Six databases were searched with inclusion criteria of trials or studies involving children who are blind or vision impaired, and impact on academic or school performance — including reading and literacy. 1262 articles were identified, with 61 papers undergoing full screening. Quality appraisal was performed using Critical Appraisal Skills Program (CASP) and seven articles deemed eligible for inclusion.
Results: Included articles achieved a quality score of over 70 % using the CASP checklists. Direct comparison of articles was not possible due to methodological differences in assessing reading and literacy levels. All seven studies investigated aspects of reading speed, with additional measures of reading performance, such as reading reserve, comprehension, and reading accuracy.
Discussion: Underlying trends highlighted students with a vision impairment do not perform at same level as their normally sighted peers with respect to reading performance - in terms of speed, but not ability. Additionally, early intervention to enhance literacy skills may help improve educational outcomes. Future direction should be aimed at identifying specific obstacles to learning these students face and providing interventions to improve academic outcomes.

Introduction

Childhood vision impairment is a condition that can significantly impact all areas of a child's development, with education playing a critical role in determining their overall quality of life[1] and long term social and economic position.[2,3] A child with a vision impairment is more likely to live in deprivation, have negatively impacted emotional and social wellbeing, and have reduced opportunities for future employment, which contributes to an increased financial burden on society through support.[4-8] Children with a vision impairment are also more likely to have autism spectrum disorder as a comorbidity with their reduced vision.[9]

In 2019 The World Health Organization (WHO) Report on Vision highlighted the importance of good vision in the development of children and adolescents.[2] From cognitive

* Corresponding author at: Caring Futures Institute, Flinders University, PO Box 2100, Adelaide SA 5001, Australia.
E-mail address: Lynne.Loh@flinders.edu.au (L. Loh).

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and social development, motor skills, coordination, and balance, to the ability to access education and achieve optimum academic success. This ultimately facilitates participation in the workforce which contributes to economic productivity and fosters a positive sense of identity for the individual.[2,3] The WHO defines vision impairment as best corrected visual acuity worse than 6/12 (mild impairment), worse than 6/18 (moderate impairment) and worse than 6/60 as severe. Blindness is defined as having a best corrected visual acuity level of less than 3/60.[2]

The prevalence of childhood blindness is estimated to be 1.4 million worldwide with an additional 19 million children categorized as vision impaired - a high proportion of these (31 %) owing to an inherited condition.[10,11] Prevalence is higher in lower income countries than higher income countries and can range from 0.1/1000 – 1.1/1000 children respectively.[4] In developed countries, major causes of vision impairment are the result of cortical vision impairment, optic nerve anomalies, albinism and hereditary retinal dystrophies.[4,10-13] Retinopathy of prematurity, cataract, glaucoma and non-accidental injury are the most common avoidable causes.[10]

Children with a vision impairment are commonly categorised and receive academic support based on best corrected visual acuity and/or visual fields, which broadly correspond to the WHO's definition of blindness and vision impairment. Studies have shown that these measures can be inaccurate indicators of visual performance, particularly in children, as visual acuity measures can be variable depending on the testing methods.[14-17] Furthermore, distance visual acuity is not the most relevant aptitude required within the classroom environment, as classroom time necessitates a high proportion of visual tasks that are predominantly based on near vision.[18] Therefore, distance visual acuity may not provide the best measure for fully describing the child's overall visual ability or performance within the classroom. Childhood vision impairment is also a complex entity as different pathologies present with different visual abilities. The term blindness is also a confounding term as many "blind" children have some functional vision.[19]

The educational challenges faced by children with a vision impairment vary considerably. In addition to reduced visual acuity, pathogenic factors significantly contribute to a student's visual ability, in terms of font requirements, contrast and lighting.[20]

To accommodate students with a vision impairment, a common classroom adaption involves enlarging the font size to enhance reading comfort. Whittaker (1993) investigated the visual requirements for reading and determined four factors that affected reading rate: acuity reserve (print size compared with minimum reading acuity), contrast reserve (print contrast relative to contrast threshold), field of view, and the presence and size of any central scotoma.[21] Bailey et al. (2003) demonstrated that the size of reading print is a significant factor in reading speed, emphasising that the ability to optimise font size for children provides a better opportunity for increased reading speed. However, studies have also shown that making the font size too large can decrease reading speed. This is because when letters are imaged too far in the periphery of the retina, resolution decreases, leading to a decline in reading speed.[22]

As children progress through school to higher years, these visual demands increase as workloads increase. Highlighting the importance of the provision of adequate accessibility strategies to enable vision impaired students to continue learning at the same rate as their sighted peers, particularly as workloads increase in later schooling years.

Previous studies have examined the consequences of uncorrected refractive error and the negative impact they have upon on academic achievement. In a study by White et al. (2017), which involved 109 Grade 3 students in Australia, thirty percent of students that were referred for further screening also scored lower on national standardized testing.[23] Narayanasamy et al. (2014, 2015) used simulated refractive errors and demonstrated that even low levels of hyperopia and astigmatism resulted in reduced reading speed, reading accuracy, comprehension and visual processing, highlighting the importance of optimal vision for academic success.[24,25]

Upon leaving education, and despite employment opportunities improving over time for students who are blind and vision impaired, a gap still exists between the employment rates of individuals who are blind or vision impaired compared with normally sighted individuals - which are still less than 50 %.[26] Individuals who are vision impaired are also at an increased risk of suicide later in life compared to the general population, which is further increased in those reporting poorer self-rated health issues.[27] Further studies have found that reduced vision results in a significant impact on self-rated health as adults.[7,28] A child born with a vision impairment is also more likely to be hospitalized or die during childhood[9,11,26] and score low on the Health-Related Quality of Life.[3,27-32]

This review evaluates the literature regarding the influence of childhood vision impairment on reading, literacy, and educational performance within the classroom setting. It investigates the literature to understand the processes by which students with a vision impairment learn to read in comparison with normally sighted students. It also explores the impact that vision impairment has on learning and discusses how this may affect educational outcomes.

Methods

This systematic review was registered with Prospero (https://www.crd.york.ac.uk/prospero/) database number: CRD42020172342.

Search strategy

A search of six databases was performed in the following databases: Ovid Medline (R) and Epub Ahead of Print, In-Process and Other Non-Indexed Citation, Daily and Version(R) 1946 to May 1st 2023, Cochrane Library, Emcare, Web of Science, Scopus, ERIC (Institute of Education Services). No date restrictions were used. References of all relevant articles were hand searched. See Table 1 for search terms used in the databases. A final search of the databases was performed on the 1st May 2023 for any recent publications.

Inclusion criteria

Trials or studies included in this review involved children aged 5–18 years who had received a pathological vision

Table 1 Keywords and search terms used.

Keywords	Search terms
Children	Child*, adolescent, youth, young people
Vision Impairment or blindness	Visual* acuity, visual* performance or Vision impaired, Visual* impaired vision disorders, blindness, low vision
School	School*
Classroom	Class*
Education	Education*
Literacy	Literacy, reading, writing
Education Performance	education performance, school performance, classroom performance, academic performance, education* impact, school impact, classroom impact, academic impact, education* improvement, school improvement, classroom improvement, academic improvement "education* success" or 'school success" or "classroom success" or "academic success"}

Table 1. Keywords and search terms used. Searches were limited to human subjects and conducted in the English language up until May 2023.

diagnosis and were classified as blind or vision impaired according to the WHO criteria.[2] The trials or studies focused on examining the effects of vision impairment on academic and school performance, specifically in areas such as literacy (including reading and comprehension), writing skills, access to information, and overall classroom performance.

Exclusion criteria

Studies were excluded if children had co-morbidities, such as additional sensory or cognitive disability, or if they had a diagnosed reading disability (dyslexia). Studies from developing countries were not included due to variable levels of education and healthcare available within these countries, making it challenging to draw direct comparisons.[33-35]

Additionally, studies involving preschool-age children were excluded, as the focus was on examining the impact of vision impairment on learning specifically within the school environment.

Study selection

Database searches revealed 1262 articles, with an additional article identified by personal communication. Articles were imported into EndNoteX9 and after duplicates were removed and seven additional papers identified from hand searching, 1043 titles and abstracts were screened for obvious ineligibility. Sixty-one remaining articles then underwent full-text screening against eligibility criteria by two of the authors (LL and MPS), with a third author available (PC) if agreement was not reached. Of those articles, seven papers were eligible for inclusion (See Fig. 1 for Prisma flow diagram of searches).

Although the search strategy identified articles that investigated measurable academic outcomes and the impact on mathematical grades, these studies investigated the impact of uncorrected refractive error in children and were excluded.[23,36] The papers included for review were therefore limited to articles that investigated reading and literacy skills in children specifically with a diagnosed vision impairment that was non-refractive error in nature.

Quality appraisal

To assess the quality of each study and to determine eligibility for inclusion, the Critical Appraisal Skills Program (CASP) was used because it has separate checklists to evaluate the quality of varying study methods.[37] Studies were included if they were deemed valid following appraisal with the relevant CASP checklist. CASP does not use a standardised numerical scoring system. Instead, it employs a series of questions designed to guide the user through the critical appraisal process. Questions are answered as a "yes", "no" or "can't tell" response. To enable the selection of studies, a scoring system was designed as a tool to confirm agreement between authors and determine the quality of studies included.

Results

Included studies

Using CASP themes, studies were assessed for clear study focus, appropriate methodology, confounding factors, and validity of results. Limitations and risk of bias were also considered and an assessment of high, medium, or low bias was subsequently determined (see Table 2). Studies were scored on quality with green scoring 2 points, yellow 1 point, and red 0 points. Scores from all three authors were compared and discussed until agreement was reached. Scores were then converted into percentage values with all articles achieving a quality score of over 70 %. Small participant numbers, recruitment methods, methods of visual acuity measurement, methods of reading analysis measurement and missing data from studies were the main causes of bias. Two studies did not specify visual acuity measures but were determined eligible for inclusion as all participants had been previously diagnosed with a vision impairment by an ophthalmologist.

Study designs varied, one longitudinal study investigating the impact of optical devices over a four to six-month period,[38] three case control studies,[39,40,41] two case series[42,43] and one interventional study used crowding training.[44] Visual acuities ranged from 0.10 −1.70 LogMAR, with two papers not specifying visual acuities.[39,41] Participant numbers varied from 6 to 158, and ages also varied from 6 to 18 years. Vision impaired children were recruited predominantly from either mainstream schools or specialist vision impaired institutes. Countries included The Netherlands (3), The USA (2), England (1) and Australia (1). A summary of demographics is detailed in Table 3.

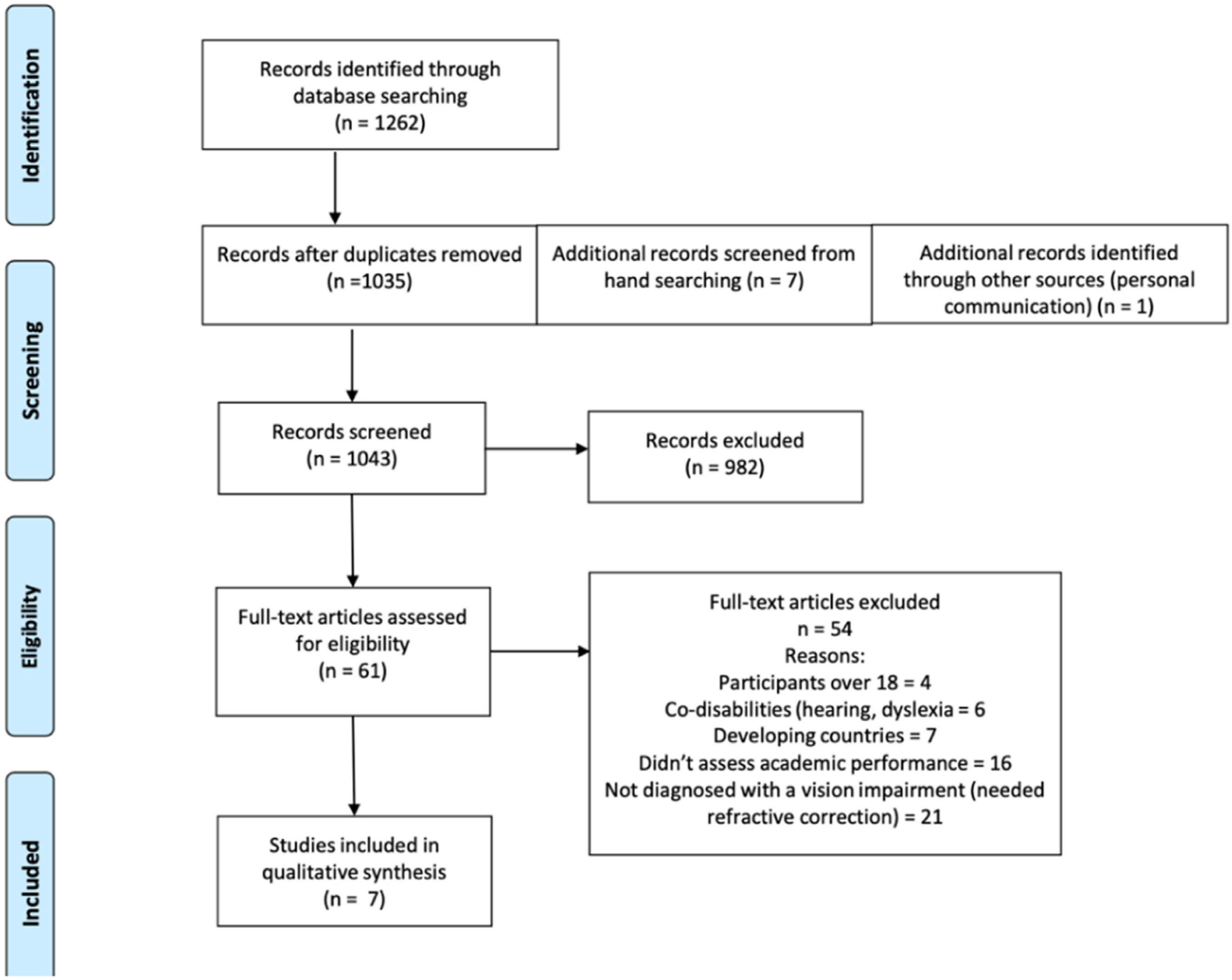

Fig. 1 PRISMA flow diagram of final literature search results showing the number of included and excluded studies following screening.

Due to the large variation in participant numbers, ages, visual acuities, causes of vision impairment, methodological differences and outcome measures, a direct quantitative comparison of the findings was not possible. All papers investigated reading performance and used varying methodologies to determine reading speed as a primary outcome measure. Alternative measurements of reading ability were comprehension,[38,39] reading acuity/print size,[40-42] and reading accuracy or reading errors.[39,43,44] (See Table 4 for details).

Reading speed

All seven included studies investigated reading speed. The majority analysed reading speed while reading continuous text,[38,39,41-44] whereas one study investigated the speed of naming single words.[40] There was consensus amongst all studies that reading speed was slower in children with a vision impairment compared with their age matched peers, and common findings that reading speed increased with age,[38,43] and with an improvement in visual acuity[38,42,43] - although visual acuity was noted as distance in two studies,[38,42] and near in one.[43] Two studies compared the reading speed of text to single words and discovered contradictory results, with one finding text reading faster,[42] and the other single words.[41] (See Table 5 for details).

Reading reserve

Three studies investigated reading reserve - the relationship between minimum font size read and critical print size (the smallest font read at maximum reading speed). Reading reserves differed across all these three studies and ranged from 1.6 to 7.0 times.[42,43] (See Table 5 for details).

Comprehension

Two studies examined comprehension by children with low vision.[38,39] It was found, in terms of reading ability, that students with a vision impairment demonstrated a generalized

Table 2 CASP checklist assessment.

Study	a	b	c	d	e	f	g	Score
Corn et al.[38]	Yes	Yes	Yes	Medium	High	Medium	Low	71 %
Douglas et al.[39]	Yes	Yes	Not sure	High	Low	Low	Medium	71 %
Bosman et al.[40]	Yes	Yes	Not sure	Low	Low	Low	Medium	86 %
Gompel et al.[41]	Yes	Yes	Not sure	Medium	Low	Low	Medium	76 %
Lueck et al.[42]	Yes	Yes	Yes	Medium	N/A	Low	Low	92 %
Lovie-Kitchin et al.[43]	Yes	Yes	Yes	Low	N/A	Low	Medium	92 %
Huurneman et al.[44]	Yes	Yes	Yes	Medium	Low	Low	Low	93 %
a, b, c	Yes		Not sure		No		N/A	
d, e, f, g	Low		Medium		High			

Table 2. CASP checklist assessment including themes of (a) Clear Study Focus (b) Appropriate Methodology (c) Validity of Results (d) Recruitment Bias (e) Control Bias (f) Outcome Bias (g) Confounding Factors, (N/A) not applicable.

lag in comprehension ability, compared to their normally sighted peers. Corn *et al*[38] additionally found an increase in comprehension ability following optical device use over a four-month period, which was more apparent in younger participants from grades 1–3. (See Table 5 for details).

Reading process, reading accuracy, and reading errors

Three studies investigated the reading processes adopted by children with a vision impairment.[38,41,43] Douglas *et al*[39] found that the students with a vision impairment tended to make more substitution errors than mispronunciation errors than the normally sighted group, which was theorized was a result of guessing. Whereas the younger control group of normal vision readers made more mispronunciation errors than substitution. However, these findings were contrary to the other two studies[40,41] that found reading processes were not significantly different to the students of the same reading-matched group and were slower but equally accurate. Gompell *et al*[41] also found that children with a vision impairment relied more on sentence context than on word phonology. (See Table 5 for details).

Discussion

The aim of this systematic review was to evaluate the literature surrounding the impact of childhood vision impairment on educational performance within the classroom setting. The evidence surrounding this is scarce, with articles primarily focussing on the impact vision impairment has on reading. However, all articles included in this systematic review achieved a quality score of over 70 % using the CASP checklists. Despite an inability to perform a synthesis of the results owing to different outcome measures and methodological differences between the studies, this review has highlighted a difference in reading and literacy skills between students with a vision impairment and their sighted peers. All seven papers analysed reading ability and demonstrate children with a vision impairment read at a slower rate than their normally sighted peers. Reasons for this could be that vision impaired children are exposed to less incidental reading than their normally sighted peers. Reading advertisements and notices in shop window, on buses or trams and reading road signs are just a few of the many ways that reading is reinforced and practiced in normally sighted children. Bosman *et al.*[40] highlighted that vision impaired children employed the same phonetical learning strategies as a normally sighted child, but they were limited by the practice that was taken for granted during incidental reading of a child with normal vision. Literacy skills have been shown to be a good indicator of future academic performance[45,46] and early literacy (and competency in mathematics) begins its development in early childhood prior to formal educational learning. These early literacy skills, developed before a child begins school, have been shown to be important factors in the development of reading ability.[47] It is therefore possible that the lack of early, incidental practice for children with a vision impairment results in reduced development of these early literacy skills and initiates the gap in reading speed ability between them, and children with normal sight, as they begin their education journey. This theory is reinforced in a study by MacDonald *et al.*[48] who evaluated a group of children and adults with albinism to determine whether vision impairment impacted the development of reading skills. Although they observed that reading speed was slower, they found comprehension skills were normal. Indicating that vision impairment with normal cognitive ability, does not impact the acquisition of normal reading skills.

Commonly, support for a child with a vision impairment is based around distance visual acuity. However, it has been shown that the majority of time in a classroom is based around near vision tasks.[18] Determining the optimal print size for reading is therefore essential to maintain engagement in classroom learning throughout the day. Lueck[42] discovered that when print size was not optimal there was a significant drop in reading speed which was more apparent for the faster readers, in contrast to slower readers who

Table 3 Demographics of included participants.

Study Country	Number of Participants (Male:Female)	Age in years SD: standard deviation	Visual Acuity of Participants Diagnosed with a Vision Impairment	Visual Acuity Test Used
Corn et al.[38] USA	*n* = 185 Vision Impaired (122M:63F).	Average age 10.54 (SD 3.85)	20/32–20/1000 (LogMAR 0.20–1.7) Groups of Low Vision severity: Near normal 20/32–20/63 (*n* = 28)/ Moderate 20/80–20/180 (*n* = 69)/ Severe 20/200–20/400 (*n* = 72)/ Profound 20/500–20/1000 (*n* = 15)	Feinbloom Low Vision Chart at 10 feet.
Douglas et al.[39] England	*n* = 50 25 Vision Impaired. 25 Normal Vision. (14M:11F)	Low vision 6:5–14:3 (mean 10.4). Normal Vision 7:8–10:6 years (mean 8.67)	Visual Acuity not specified. Diagnosed vision impairment.	Not specified
Bosman et al.[40] The Netherlands	*n* = 54 18 Vision Impaired (6M:12F). 26 Normal Vision: 18 Age-matched. 18 Reading-matched.	Low vision: mean age 10.5. Reading matched normal Vision: mean age 9. Age matched 10.4.	20/50–20/250 (LogMAR 0.4–1.10)	Visual acuity test not specified Lea Symbol Distance Visual Acuity Test.
Gompel et al.[41] The Netherlands	Total 120 40 Vision Impaired. 80 Normal Vision: 40 Age-matched. 40 Reading-matched.	Ages not specified. Participants selected from a previous study: mean age 9.5	Visual acuities not specified. Diagnosed vision impairment.	Visual acuity test not specified
Lueck et al.[42] USA	*n* = 6 (3M:3F).	8–10	Distance Visual Acuity: 20/160–20/600 (LogMAR 0.9–1.50) Reading Acuity: 20/66–20/1162	Lea Symbol Distance Visual Acuity Test.
Lovie-Kitchin et al.[43] Australia	*n* = 75 Vision Impaired (42M:33F)	7–18	Distance: 0.10–1.28 LogMAR Near Visual Acuity: 0.12–1.47logMAR (N1.5-N24 at 10 cm).	Bailey-Lovie letter chart at 3 m (or closer if visual acuity was less than 6/120)
Huurneman et al.[44] The Netherlands	*n* = 36 Vision Impaired	Albinism: 9.25±19 months Infantile nystagmus: 9.1 ± 18 months.	Albinism: 0.47±0.30 LogMAR uncrowded, 0.66± 0.05 LogMAR crowded. Idiopathic Infantile Nystagmus: 0.25±0.17 LogMAR uncrowded, 0.46± 0.05 LogMAR.	Crowded and uncrowded Landolt C, measured at 5 m for distance and 40 cm for near.

Table 3. Demographics, including participant numbers, country, participant ages, visual acuity ranges and visual acuity tests used – where specified: M: Male; F: Female; n: Number of participants; SD: Standard Deviation.

read slowly across all font sizes until speed dropped abruptly. Huurneman *et al*[44] investigated the difference in these characteristics between children with albinism and infantile nystagmus, finding that reading acuity was worse in children with albinism than infantile nystagmus – even after accounting for visual acuity measures. They also found children with a larger crowding extent (the difference between crowded and uncrowded acuity), required a larger critical print size as crowding effected letter and word recognition.

Corn *et al.*[38] demonstrated a significant increase in reading speeds in years 1–3 of school following the use of an optimal optical device over a four-month period, which highlights the importance of improving accessibility to reading materials during early primary years. That coupled with

Table 4 Outcome measures.

Study	Outcome Measures	Test Used
Corn et al.[38]	Change in reading and comprehension ability before and after using optical devices. (153 students [82.7 %] had assistance of specialist teachers of vision impairment).	Silent and oral reading speeds and comprehension levels measured using the Burns & Roe Informal Reading Inventory (1993)
Douglas et al.[39]	Reading speed, comprehension and reading errors.	Neale Analysis of Reading Ability (NARA)
Bosman et al.[40]	Speed of first letter phonology naming. Time and accuracy naming single words.	The Netherlands standardised reading-decoding one-minute test (Brus & Voeten 1973)
Gompel et al.[41]	Identification of constituent letters of a word and the processing of letter order information in words. Naming latency and accuracy recorded.	Standardised three minute word decoding test (DMT, Verhoeven,1995)
Lueck et al.[42]	Reading speed and working distance for students with low vision.	MNREAD Acuity Charts
Lovie-Kitchin et al.[43]	Reading rate (wpm) for each print size. Maximum oral reading rate. Near visual acuity: smallest print size read in LogMAR. Critical print size. Reading reserve.	Minnesota Low Vision Reading Test on printed cards.
Huurneman et al.[44]	Reading performance: acuity/ critical print size/ maximum reading speed (wpm)/ reading reserve/ crowding intensity. Administered crowding and uncrowded training to determine effect of training on reading performance.	Sentences of a Dutch Reading chart (LEOntienje) presented on a computer screen.

Table 4. Summary of primary outcome measures from each included study and reading tests used: *Critical Print Size*: Smallest font that can be read at maximum reading speed. *Reading Reserve*: ratio of critical print size to smallest font size read. *Crowding Intensity*: ratio of crowded acuity to uncrowded acuity. *Reading rate* in words per minute (wpm).

their results of higher comprehension scores, where older students did not show as marked improvements, highlighted that improving accessibility to reading material at an earlier age during the ‘learning to read’ process, had a more marked effect on reading ability. This finding supports the importance of early intervention and the impact of support on early reading and comprehension. However, the study did not consider any support or specialist training the students may have received over this four-month period. The study authors acknowledged that some of the students did have specialist vision support teachers which may have impacted the findings.

Focus groups of children who are vision impaired mention a dislike of reading,[31] perhaps because this visual task is challenging and requires extra effort, possibly resulting in additional visual fatigue and tiredness.[49] This reluctance to read beyond requirements, in contrast to normally sighted children, presumably also limits any recreational reading at home and adds to the lack of reading practice children with a vision impairment undertake outside of the classroom. Khadka *et al.*[31] also identified a voiced need for children with a vision impairment to be independent and felt, at times, limited in this independence by parents and support teachers. Accentuating a need for support based around independent accessibility and the need for children with a vision impairment to develop their independence skills that can be used for education and beyond. A recent systematic review of the factors relating to employment outcomes of students with a vision impairment found that education level had a positive effect on employment level and future earnings of vision impaired students, emphasizing the necessity of optimal education for future outcomes.[50]

This review draws attention to fifteen years of research indicating a generalized lag in the reading ability of students with a vision impairment compared with their normally sighted peers in terms of reading speed. Despite this there is no definitive criteria for support that is acknowledged and accepted worldwide. Many countries have systems for support within classrooms and some countries have specialist vision impairment teacher training centres to enhance support within the classroom. Often though, this task is left to a class teacher with minimal knowledge of vision impairment and its effect on a child’s visual ability.

Vision impairment can result in significant visual fatigue during a school day within a classroom environment, which can manifest in different ways – headaches, tiredness or it can be changes in behaviour during the day.[49] Teachers often struggle to determine if, or what, aspects are due to vision. Primary educators may not have extensive experience of vision impairment and can be faced with the difficult task of translating a visual acuity result or visual field analysis into a functional measure of the child’s vision performance in class. Visual acuity is a measure of the eyes resolving ability and does not provide comprehensive knowledge around

Table 5 Reading characteristics.

Study	Reading speed
Corn et al.[38]	Silent and oral reading speeds were slower than normally sighted peers. After using optical devices over 4 months, there was a significant increase in silent reading speeds — more apparent at lower year levels. Reading speed decreased with reduced visual acuity. Increase in reading rate with increasing year level.
Douglas et al.[39]	Students with a vision impairment demonstrated a general lag in reading speed compared with normally sighted peers.
Bosman et al.[40]	Students with a vision impairment were slower at reading single words than their normally sighted peers.
Gompel et al.[41]	Reading speed for text and single words was slower in students with a vision impairment than normally sighted peers. Single words were read faster than text.
Lueck et al.[42]	Reading speeds increased with increased visual acuity. Reading speeds decreased with decreasing print size. Reading speeds for text, faster than non-related words.
Lovie-Kitchen et al.[43]	Reading rate increased with increasing age. Reading rate increased with improved near visual acuity.
Huurneman et al.[44]	Children with infantile idiopathic nystagmus had a lower reading speed compared with children with albinism — both read slower than their normally sighted peers. Following crowding training, both groups read faster.
	Reading Reserve
Lueck et al.[42]	A reading reserve of 1.6 — 2.5x reduced reading speed. Recommended reading reserve of 3x to be used by children with low vision.
Huurneman et al.[44]	Children with larger crowding extent required larger critical print size and reading reserve.
Lovie-Kitchen et al.[43]	Children with a lower near visual acuity had a smaller reading reserve. Recommended an optimum reading reserve of 4x. 56 subjects (75 %) required a reading reserve of between 2.5—7x.
	Comprehension
Corn et al.[38]	General lag in comprehension level compared with normally sighted peers. An improvement in oral comprehension was demonstrated following optical device use for four months. Silent comprehension also improved over the four months period, but not as much as oral.
Douglas et al.[39]	General lag in comprehension level compared with normally sighted peers.
	Reading process, reading accuracy, and reading errors
Douglas et al.[39]	Children with a vision impairment more likely to make substitution errors than mispronunciation errors.
Bosman et al.[40]	Reading behaviour of low vision group same as (younger) reading matched group, but lower than age-matched group. Reading process of students with low vision differed quantitively (speed) and not qualitatively.
Gompel et al.[41]	Children with a vision impairment rely more on sentence context and demonstrated the same reading ability as normally sighted readers — just slower.

Table 5. Summary of main findings of reading measures from each included study included: *Reading Reserve*: ratio of critical print size to smallest font size read. *Crowding Extent*: ratio of crowded acuity to uncrowded acuity.

functional visual ability to enable adequate support within a classroom environment that is dominated by near tasks. Reading, writing, and literacy skills are essential foundations that are crucial for education, and the ability to achieve optimal educational outcomes is inherently determined by the ability to master these basic building blocks to learning. Strong literacy skills have been found to have a significant impact on future academic achievement,[45,47] and literacy and mathematical ability have been shown to be related over time with a difficulty in one area often associated with difficulty in another.[47]

Study limitations

This review was limited in several aspects. Studies were excluded from developing countries due to the variation in healthcare and resources in these countries, which may impact the adaptation of review findings. The search specified studies in English only which may have resulted in studies of other languages being excluded. The studies also utilized several different methods for measurement of visual acuity and analysis of reading. These differing outcome measures resulted in the inability to draw comparisons across studies. Two studies did not specify visual acuity measures but were included due to a diagnosis of vision impairment, which may have biased some of the study results. As participant recruitment was either from specialist vision impairment schools or mainstream schools, the students from specialist schools may have received more specialist vision support within the classroom which may have additionally biased results obtained.

Conclusion and future directions

The evidence surrounding educational outcomes for vision impaired children is limited by the level of available studies. The inability to synthesize results makes it difficult to form a quantitative appraisal of the current literature and a definitive answer to this review question. Although the studies included in this review indicate that reading and literacy skills for vision impaired students lag behind their normally sighted peers in terms of reading speed, a comprehensive longitudinal study would provide more substantial evidence and inform educators surrounding areas of need.

One potential future direction could be a standardised functional assessment aimed at identifying specific visual deficits and abilities within the classroom, then using individualised intervention approaches aimed at increasing independent accessibility skills.

A second potential future direction could be then categorising childhood vision impairment based on functional ability. A system which enables the provision of in-depth information on a child's visual ability would be invaluable to educators and parents. It would provide educators with more information surrounding the difficulties a vision impaired child faces accessing educational information, enabling teachers to address these issues and help reduce the gap between them and normally sighted peers. A recent case study highlighted that an assessment of functional vision and tailored supports improved accessibility to the curriculum in the classroom for a student with cone dystrophy.[20] This ideally should be enabled at an early age to develop early literacy skills, encourage independent accessibility skills and build the foundations required for continuing education or employment.[38]

Conflicts of interest

The authors declare no conflicts of interests. This study was not funded.

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Supplementary materials

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CLINICAL COMMUNICATION

Cone dystrophy, childhood vision impairment and education: are clinical measures of visual function adequate to support a child through education?

Lynne Loh* MSc, Anna Gatsios* BSc (Vis Sci), MOptom, Mallika Prem-Senthil* PhD, Paul A Constable* PhD

*Caring Futures Institute, College of Nursing and Health Sciences, Flinders University, South Australia, Adelaide, Australia.

Corresponding Author

Lynne Loh, College of Nursing and Health Sciences, Flinders University, PO Box 2100, Adelaide SA 5001, Australia, ORCID: 0000-0002-1357-9395.

Keywords: Cone Dystrophy, Visual Acuity, Visual Function, Education, Quality of Life, Reading

INTRODUCTION

This case report highlights the need to re-evaluate standard measures of distance visual acuity and visual fields in a child with a vision impairment, particularly the relevance these measures have on learning within the classroom environment. Performance with near tasks such as reading speed, print size requirements and contrast sensitivity are not routinely measured for children with a vision impairment. These additional functional measurements of visual performance can be used to identify areas causing accessibility deficits within the classroom. Identifying functional measures can contribute to improved support for the child, thereby improving their accessibility to the curriculum alongside their normally sighted peers.

Retinal dystrophies result in progressive degeneration of photoreceptors and consequent gradual loss of visual acuity and visual fields. The impact of retinal dystrophies on daily living activities has been investigated within adults, with difficulties found to be related to standard clinical measures of visual function, such as visual acuity, contrast sensitivity, electrophysiological findings and visual fields.[1,2] Clinical measures have also been found to correlate with observed task performance and self-reported performance.[1] However, these adult populations investigated the effect on activities such as employment, travelling at night and driving which are not pertinent to children in education with a vision impairment.

Clinical measures are essential for the initial diagnosis and categorisation of level of vision impairment, this information similarly determines the degree of support a child will receive during their education. Within South Australia, support levels for children with a vision impairment are currently based on visual acuity and visual field extent, which broadly correspond to the World Health Organisation definitions of Blindness and Vision Impairment. This approach does not consider the functional impact of a child's specific visual impairment and does not reflect how the individual visual diagnosis impacts their overall visual performance within the classroom. Factors such as room illumination, print size, colour and contrast can influence visual function and the capacity for the child to access educational materials.

This case report describes a 13-year-old girl (AR) with a cone dystrophy who has just transitioned from a specialist vision impairment school into a large mainstream high school in South Australia. It investigates differences in the standard visual function tests and compares these metrics to AR's visual performance, including the self-reported impact it has on AR within the school environment.

CASE REPORT

Medical History

AR, a 13-year old female, was delivered at thirty-five weeks and at a routine post-natal twelve-week check, nystagmus was noted. At six months, cone dystrophy was diagnosed based on electrophysiological measures. AR has a distant family history of Retinitis Pigmentosa on her maternal grandfathers' side. No genetic testing has been conducted to date. A comprehensive assessment of visual function was performed to evaluate AR's current level of performance, and she was interviewed regarding self-reported visual ability, using the Cardiff Visual Ability Questionnaire for Children,[3] and the impact it has on her educational learning.

Clinical/Diagnostic Tests

AR's refractive error was right eye: -2.25/-4.50x15 and left eye: -1.75/-2.00x160. Visual acuity was measured using the Freiburg Visual Acuity Test (FrACT).[4] FrACT is a computer based visual acuity test, widely used in clinical trials. It has been extensively tested and correlates highly to EDTRS LogMAR charts. It can accurately quantify visual acuity in the lower range, measures reaction time and can be used at any test distance.[5] It employs a Landolt C, making it suitable for young children, and visual acuities can be measured with a crowded or uncrowded target – which can indicate difficulty with visual clutter. Monocular crowded visual acuities were Right:1.04 LogMAR ($6/60^{-}$) and Left: 0.98 LogMAR (6/48). AR has manifest nystagmus, with a left preference alternating exotropia.

A central 30-2 threshold visual field test (Humphrey HFA-II, Carl Zeiss, Oberkochen, Germany) revealed generalised reduction in sensitivity for the right eye -7.60 dB and for the left eye -8.70 dB with a high false negative test index. Fundus photography, fundus autofluorescence and macular optical coherence tomography (See Figure 1) were performed using the Zeiss Cirrus 5000 (Carl Zeiss, Oberkochen, Germany). Optical coherence tomography and retinal photography revealed retinal atrophy with inner retinal thinning and focal macula hyperfluorescence (left eye greater than right). See Supplementary Material for full reports.

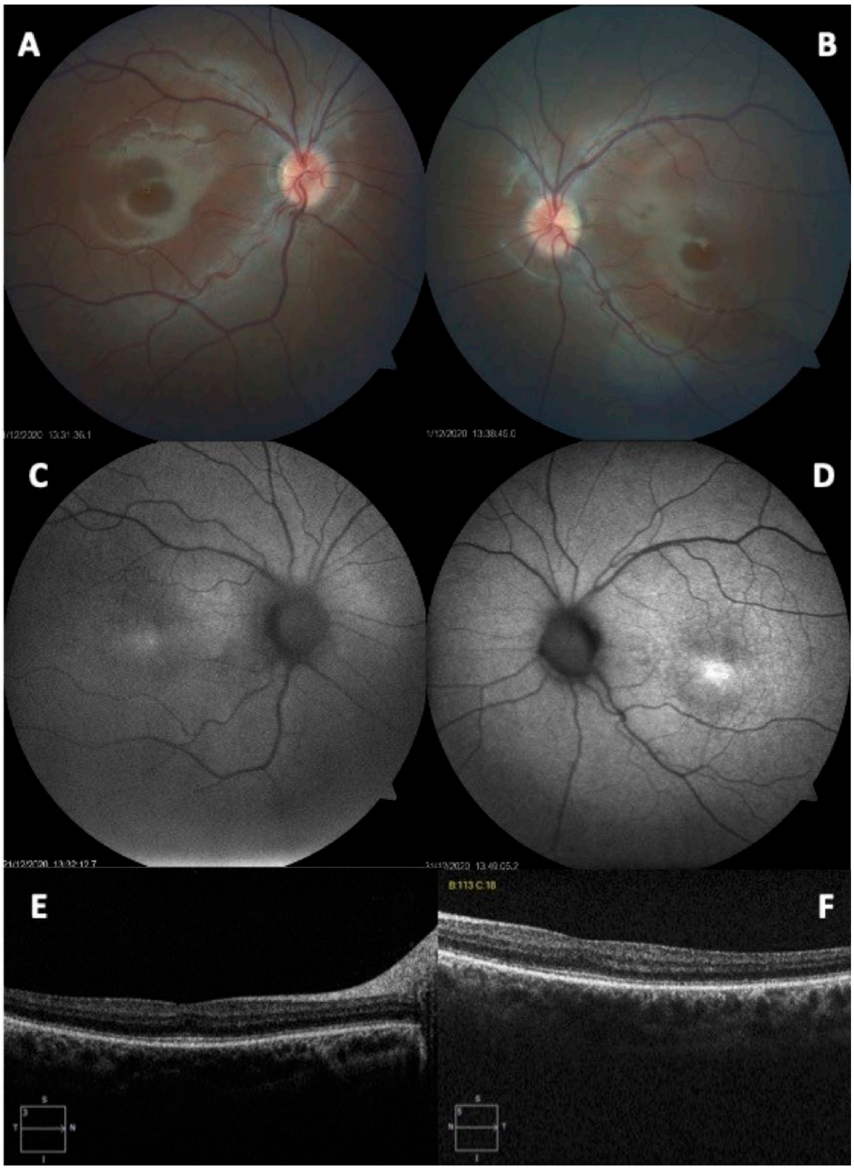

Figure 1. Figures A and B show the right and left eye fundus photographs with no marked retinal anomalies. Figures C and D show fundus autofluorescence with hyperfluorescence (left greater than right) indicating retinal pigment epithelial stress. Figures E and F show macular scans with normal foveal architecture.

Functional Vision Tests

Binocular crowded visual acuities were measured under differing ambient light levels using Lux LightMeter App on an iPad7, iOS version 14.4.1. Under photopic illumination (450 lux): 0.85 LogMAR (~6/45) and improved under mesopic illumination (10 lux) to: 0.78 LogMAR (~6/38). Resolution threshold contrast sensitivity (CS) was measured using FrACT Contrast C, [4] and revealed a reduced measure of 0.71 LogCS compared to a typical value of 1.93 LogCS. Binocular colour vision, using a standard sized D15, revealed a Tritan defect as previously reported in macular dystrophies.[6] Reading analysis was performed using the MNREAD App[7], which was developed at the Minnesota Laboratory for Low-Vision Research, University of Minnesota. It was designed to assess aspects of reading such as reading acuity, critical print size (the smallest font size read at maximum speed), accessibility to printed material and maximum reading speed. During reading, as we reach near vision resolution limits, reading speed begins to reduce rapidly. Critical Print Size is the largest font size before reading speed begins to decrease and is defined as the print size at which subsequent smaller print sizes were read at 1.96 standard deviations slower than the mean of the preceding print sizes[7] Print Accessibility Index is a value from 0 to 1, where 0 is no access to commonly printed material and 1 is normal access to printed material. It is calculated by comparing the results against the performance of normally sighted individuals, by using the mean reading speed across ten print sizes from 0.4 to 1.3 LogMAR.[8]

All reading measurements were taken at 30 cm. Using normal polarity (black text on white background) AR achieved a minimum print size of 22-point (0.90 LogMAR) and critical print size of 29-point (1.02 LogMAR). With reverse polarity (white text on black background) AR achieved a smaller minimum print size with 15-point (0.73 LogMAR) and a critical print size of 23 point (0.92 LogMAR). Additionally, at the recommended minimum font size of 23-point print with reverse polarity, AR's reading speed was 92.1 words per minute, compared to 56.8 words per minute with normal polarity. Correspondingly, the Reading Accessibility Index was higher for reversed polarity (white on black) (0.34) compared to normal polarity (black on white) (0.31) indicating an improved reading performance with reversed polarity text. See figure 2 and Table 1. Data Report.xlsx as Supplementary Material giving the full test reading report.

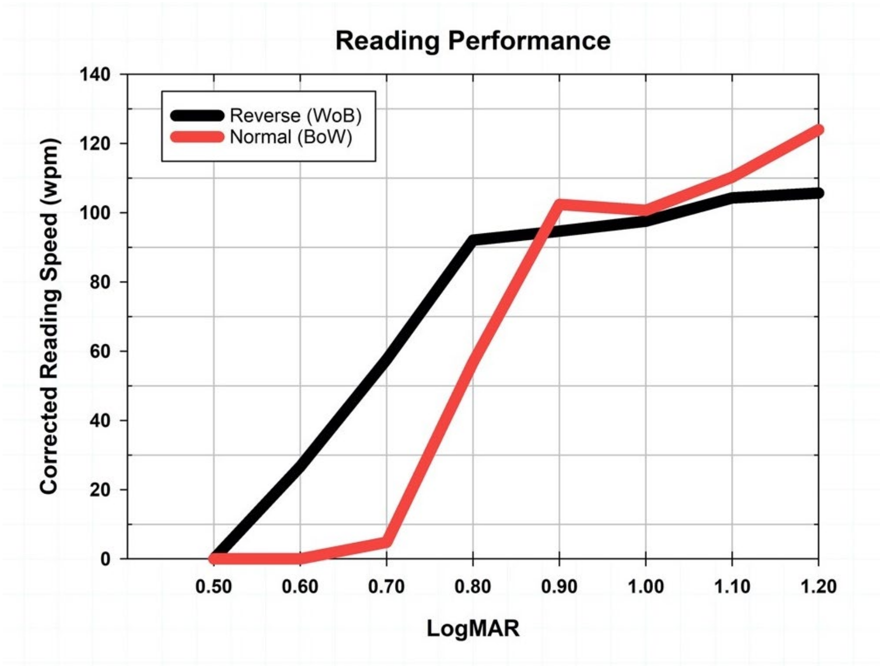

Figure 2. The effects of reversed polarity (White text on Black background (WoB) Black line and normal polarity (Black text on White background (BoW) Red line on reading speed. The sharp drop in reading speed is apparent once critical print size is reached. With the Reversed polarity AR was able to read smaller text and critical print size was smaller.

Reading Test Parameters at 30 cm	Normal Polarity	Reversed Polarity
Reading acuity LogMAR (Print size)	0.90 (22)	0.73 (15)
Critical Print Size LogMAR (Print size)	1.02 (29)	0.92 (23)
Corrected Reading Speed at 23-point print (words per minute)	56.8	92.1
Reading Accessibility Index	0.312	0.342

Table 1 Summary measures of reading ability with normal polarity (black print on white background) and reversed polarity (white text on black background) for AR. Reading acuity is the smallest print size that can be read before making errors. The critical print size is the print size at which subsequent smaller print sizes were read at 1.96 standard deviations slower than the mean of the preceding print sizes. The Reading Accessibility Index is a normalised value of an individual's ability to access commonly encountered print material (0 to 1 scale) where 1= ability to read all print, and 0= no ability to read commonly printed material.

DISCUSSION

This case highlights the benefits of using functional and performance-based measures of visual ability for children in education. Results from AR's clinical measures were consistent with a previously diagnosed cone dystrophy.

Childhood vision impairment is often categorised and support levels determined according to visual acuity and visual fields, but by providing additional measures of visual performance such as reading speed, print size requirements or the effect of contrast, a more holistic picture of the individual's abilities and needs can be utilised to improve their learning performance within the classroom.

Results from functional vision tests were used to inform class teachers of expected accessibility deficits and strategies to help overcome these. Recommended adaptions included required print size (including recommendations for electronic documents with reverse polarity/colour inversion), contrast requirements, lighting requirements based on visual acuity measures from different ambient lighting, information and management of visual fatigue due to nystagmus, impact of colour vision deficit, and extra time requirements based on reading speeds. A detailed report including functional measure results, interpretation of results and suggested strategies, was provided to AR's parents and her school support team. (Recommendation examples are included in supplementary material).

Reading, writing, and literacy skills are essential foundations to learning, and accessibility to appropriate print size material can have a significant effect on a child's ability to learn at the same rate as their peers. Critical Print Size can be used to determine an appropriate print size to enable optimum reading capacity.[7] AR's critical print size was 29-point with normal polarity, which can then be used to inform AR's teachers and carers of the minimal font size to improve accessibility to printed materials. AR was able to read smaller sized print if it was brought closer, effectively magnifying the print. However, for sustained and extended near work in the classroom environment, using a closer working distance is difficult to sustain, particularly in the presence of nystagmus. Reading analysis was also performed using reverse polarity (white print on a black background). With reverse polarity, AR was able to read smaller print size and at a faster rate, and AR's reading accessibility index improved, indicating better reading performance with reversed polarity text. This information informs teachers that AR's preference for learning material is electronic documents, so she can enlarge font to a comfortable size and reverse the polarity. MNREAD charts have published reference baseline measures of reading speeds,[9] which enables the provision of advice regarding time allowances for class work and assessments.

In South Australia, this recommended print size in combination with other factors, such as reading speed, impact of visual fatigue and likelihood of disease progression, is used to determine long term provisions for support. Long term support includes introduction to Braille, audio based learning and screen reading software programs such as JAWS[®], and Orientation and Mobility requirements to ensure future independence.

During the interview, AR acknowledged a more comprehensive assessment of visual function and performance had helped to improve her accessibility to educational materials, and the positive impact it had made transitioning to secondary education. AR commented that:

"*Because I have trouble with bright light and glare, the polarity is reversed on electronic documents so it's easier, and more comfortable, for me to read."*

"I am allowed extra time for homework and exams because it takes me longer to scan and read, especially if I have a lot of reading to do."

These comments support the use of reversed polarity text for AR and reading speed analysis provided a quantitative measure that enabled AR to be given the appropriate extra reading time for her work.

This case highlights the impact of specialist support and the need for investigative assessments which include functional aspects of vision impairment, such as print size, reading speed, reading accessibility index, contrast requirements and the impact of normal or reversed polarity text, so that adequate provisions can be made for children to access their educational needs. While visual functional tests are important in confirm diagnosis, subsequent assessments should be performed to assess the individual's functional visual performance which may not correlate directly with clinical tests such as visual acuity and visual fields. These measures can be used to help provide information around optimum accessibility requirements and the necessity for future requirements that may be needed, such as Braille or audio-based technology. This is especially important for children transitioning to high school where children with vision impairment can face additional accessibility obstacles and have difficulty accessing learning material at the same rate as children without a vision impairment.[10]

Future direction would benefit from a national standardised functional vision assessment to determine visual ability for children with a vision impairment, allowing enhanced support and independent accessibility throughout education.

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SHORT REPORT

Visual search and childhood vision impairment: A GAMLSS-oriented multiverse analysis approach

Paul A. Constable[1] · Lynne Loh[1] · Mallika Prem-Senthil[1] · Fernando Marmolejo-Ramos[2]

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Abstract
The aim of this report was to analyze reaction times and accuracy in children with a vision impairment performing a feature-based visual search task using a multiverse statistical approach. The search task consisted of set sizes 4, 16, and 24, consisting of distractors (circle) and a target (ellipse) that were presented randomly to school-aged individuals with or without a vision impairment. Interactions and main effects of key variables relating to reaction times and accuracy were analyzed via a novel statistical method blending GAMLSS (generalized additive models for location, scale, and shape) and distributional regression trees. Reaction times for the target-present and target-absent conditions were significantly slower in the vision impairment group with increasing set sizes ($p < .001$). Female participants were significantly slower than were males for set sizes 16 and 24 in the target-absent condition ($p < .001$), with male participants being significantly slower than females in the target-present condition ($p < .001$). Accuracy was only significantly worse ($p = .03$) for participants less than 14 years of age for the target-absent condition with set sizes 16 and 24. There was a positive association between binocular visual acuity and search time ($p < .001$). The application of GAMLSS with distributional regression trees to the analysis of visual search data may provide further insights into underlying factors affecting search performance in case-control studies where psychological or physical differences may influence visual search outcomes.

Keywords Visual search · Reaction time methods · Statistical inference

The aim of this brief report was to investigate the impact of a vision impairment on search efficiency using a classical feature-based search paradigm (Green, 1991) with an alternative statistical analysis using distributional regression trees (Schlosser et al., 2019). Common causes of vision impairment in children include inherited retinal dystrophies, congenital glaucoma, retinopathy of prematurity, and albinism, which are frequently associated with nystagmus (Rahi, 2007; Teoh et al., 2021), and may impact the child's ability to read at a similar speed to their typically sighted peers (Loh et al., 2021). Studies in amblyopia have demonstrated worse performance for feature and conjunctive search strategies (Tsirlin et al., 2018) that are directly related to oculomotor control (Chen et al., 2018; Huurneman et al., 2014) and crowding (Levi, 2008).

Visual search studies may involve complex populations where multiple underlying factors such as visual acuity, oculomotor control, or cognitive ability may impact their search ability and contribute to the overall results. For example, in studies involving neurodevelopmental disorders such as autism spectrum disorder (ASD) where attention (Scheerer et al., 2021), oculomotor control (Pruett Jr et al., 2013), sex (Harrop et al., 2019), crowding (Lindor et al., 2018), diagnostic procedure (Almeida et al., 2010), age of the population (Constable et al., 2010), or search strategy interpretation (Keehn & Joseph, 2016) may all impact on overall performance and interpretation of the results. Similarly, in studies involving patient groups with an acquired loss of function due to neurodegeneration such as dementia or vision impairment through disease such as glaucoma or age-related macular degeneration, similar group characteristics such as the duration of the vision impairment, cortical evoked potentials, contrast, cognitive ability, or extent of

✉ Paul A. Constable
paul.constable@flinders.edu.au

1 College of Nursing and Health Sciences, Caring Futures Institute, Flinders University, Bedford Park, South Australia, Australia

2 Centre for Change and Complexity in Learning, The University of South Australia, Adelaide, South Australia, Australia

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visual field may be additional factors that impact on search performance (Lee et al., 2020; Sklar et al., 2020; Vullings et al., 2022; Xue et al., 2022) but are not readily analyzed using standard statistical analyses. Thus, the application of additional statistical analyses to search data may help in identifying underlying factors that contribute to the overall search performance in complex populations involved in case-control studies.

Whilst it is intuitive to presume that search performance will be affected in individuals with a vision impairment, there have been few studies that have explored visual search in a school-age population of individuals with a vision impairment. To confound the findings, different search tasks have been adopted to explore the impact of vision impairment on search efficiency. In a real-world paradigm, children with a vision impairment were slower to locate an object within a natural scene (i.e., a stapler in an office space; Tadin et al., 2012). Longer search times have also been demonstrated in children and adults with a vision impairment in feature-based and conjunctive search tasks that increases with the number and complexity of the distractors which is associated with the degree of oculomotor control, crowding, and extent of their functional visual field (Huurneman et al., 2014; Kuyk et al., 2005).

Further underlying factors that may affect search speed and accuracy in typical observers are attention that guides visual search based on salient features, prior experience, and the scene context (i.e., where an object of interest is most likely to be found; Wolfe, 2021). The functional field of vison has become a theoretical framework in which to describe visual search with the extent of the functional field of vision determining the number of fixations required to determine whether a feature is present or absent (Hulleman & Olivers, 2017). Distortions in the peripheral functional field of vision may enhance confusions between a target and distracter and reduce search performance (Zhang et al., 2015). These factors may play an important role in search efficiency in children with a vision impairment where visual field size and oculomotor control may be compromised and exhibit slower reading speeds (Webber, 2018). For a recent review of visual search theories, see Wolfe (2020).

Typically, a feature based visual search study would compare the reaction times, accuracy, and the slope and intercept of the reaction time versus set-size relationship to draw conclusions about search strategy and performance between groups. The slope of the relationship is related to search efficiency with the intercept to attention (Sternberg, 1966). In this study, a different approach was adopted to the analysis of visual search reaction times and accuracy for children with and without a vision impairment. Reaction times and accuracy were analyzed using a multiverse approach in which key variables were identified via algorithms for variable selection and subsequently used in a distributional regression tree (Schlosser et al., 2019); this method combines GAMLSS (generalized additive models for location, scale, and shape) modelling (Stasinopoulos et al., 2018) with decision trees. In brief, decision trees are tools in the form of directed graphs designed to support decisions based on 'if-then' conditional statements (e.g., if Condition 1, then outcome; see Breiman et al., 1984; Kamiński et al., 2017; Quinlan, 1987). GAMLSS, on the other hand, is a semiparametric regression framework capable of dealing with nonlinear relationships via smoothers and adopting any probability distribution to represent the response variable. That is, GAMLSS allows performing ordinary linear, generalized linear, and generalized additive regression but with the possibility of inspecting the effects of covariates on all the parameters of the statistical distribution representing the dependent variable (Marmolejo-Ramos et al., 2022).

In visual science, GAMLSS has been applied to generating reference curves for refractive errors (Truckenbrod et al., 2020) and to identify outliers with a population of children whose developmental profile of visual acuity differs (Stander et al., 2019). By applying a different analytical approach to this standard search task, the study aimed to identify variables that may be important to visual search in children with and without a vision impairment. These findings may be applicable to other studies in which multiple factors may affect search efficiency owing to physical or psychological differences between study populations. Such variables may include, but not limited to, attention (Scheerer et al., 2021), saccade time (Vullings et al., 2022), age (Borges et al., 2020; Xue et al., 2022), sex (Harrop et al., 2019), visual field size (Wiecek et al., 2012), visual acuity (Kuyk et al., 2005), oculomotor control (Chen et al., 2018; Huurneman et al., 2014), clinical diagnosis severity in the case of neurological disorder (Almeida et al., 2010), or crowding (Levi, 2008). Thus, GAMLSS-based decision trees may provide a useful method to identify factors that may influence search performance depending on the task.

Methods

Participants

The inclusion criteria for the vision impairment group were individuals 5 to 18 years of age with a diagnosis of vision impairment by an ophthalmologist and registered as either blind or visually impaired. Exclusion criteria were participants with co-occurrence of a neurodevelopmental disorder such as autism spectrum disorder, dyslexia, or intellectual disability and were unable to follow simple verbal instructions. Corrected binocular acuity was limited to the range of 6/9.5 to 6/190 (LogMAR 0.2 to 1.5).

A total of 39 vision-impaired individuals were recruited from the South Australian School for Vision Impaired, of which the majority of 32 (82%) had nystagmus. The mean ± *SEM* binocular visual acuity of the vision impaired group was 0.63 ± 0.05 LogMAR with range of 0.21 to 1.46 (~6/9.5–6/180) measured using the Freiburg acuity test using four alternative forced choice strategy with Landolt rings (Bach, 1996). Comparison control children (n = 33) were recruited from local schools and friends and family who had normal to near normal corrected acuities and no oculomotor imbalances. There were no significant differences between groups for age (mean ± *SEM*), vision impaired = 11.6 ± 0.5 and control = 13.0 ± 0.5 years; Mann–Whitney U, p = .052 and sex/gender (vision impaired male n = 22 [56%] and control n = 19 [61%]); $\chi^2(1) = .03$, $p = .87$. The vision-impaired group consisted of individuals with a diagnosis of albinism (n = 12), inherited retinal disease (n = 12), visual pathway disorder (optic nerve/cortical; n = 6), congenital nystagmus (n = 3), congenital cataract (n =)2, and n = 1 each of retinopathy of prematurity, myopia, anterior uveitis/cataract, or vision impairment with unknown etiology. This study was performed in line with the principles of the Declaration of Helsinki and was approved by the Women's and Children's Health Network, Human Research and Ethics Committee (HREC/19/WCHN/177), and The South Australian Department of Education (2019-0047). Written informed consent was obtained from the parent/guardian of the participant prior to taking part in this study.

Visual search

Methods for this study have been previously described in Constable et al. (2010). The target (ellipse) and distractor (circle) were presented on the display of a MacBook Air-11.6-inch display (1,366 × 768 pixels at 75Hz) with mean luminance of 65 cd.m^{-2} and the subject sitting comfortably at a viewing distance of 40 cm in dim room illumination (150–200 lx). Experiments were run using MATLAB (The MathWorks, Natick, MA, USA) and Psychophysics Toolbox extensions for stimulus generation, experiment control and recording the participant's responses (Brainard, 1997; Pelli, 1997). The circle distractors had dimensions of 0.8 cm × 0.8 cm, projecting a visual angle of 1.15° whilst the target ellipse had dimensions of 0.7 cm × 1.0 cm, projecting a visual angle of 1.00° and 1.43° (Fig. 1). The stimuli were further refined via anti-aliasing process through a Gaussian blur kernel (σ of 2 pixels) which reduced image noise and smoothed the border of the circles and ellipse.

The stimuli were equally spread on a 12 × 12 grid to allow equal number of stimuli on each side from the point of fixation. Three set sizes were used with either target present or absent consisting of 4, 16, and 24 items displayed randomly within the grid and presented randomly for each trial. At the start of each trial the participant was instructed to press the key 'P' if the ellipse was present or the key 'A' if the ellipse was absent. A total of 80 presentations were performed in each trail (8 practice plus 72 test trials). The participant was instructed to do the task as quickly and as accurately as possible.

Analysis

In this study, eight practice and 72 test trials were administered in random order for each participant. The first eight presentations were used as practice trials and were excluded from the analysis. During the practice trials, the instructor (LL) gave verbal feedback and an audible cue sounded for an incorrect response during the practice or test trials so

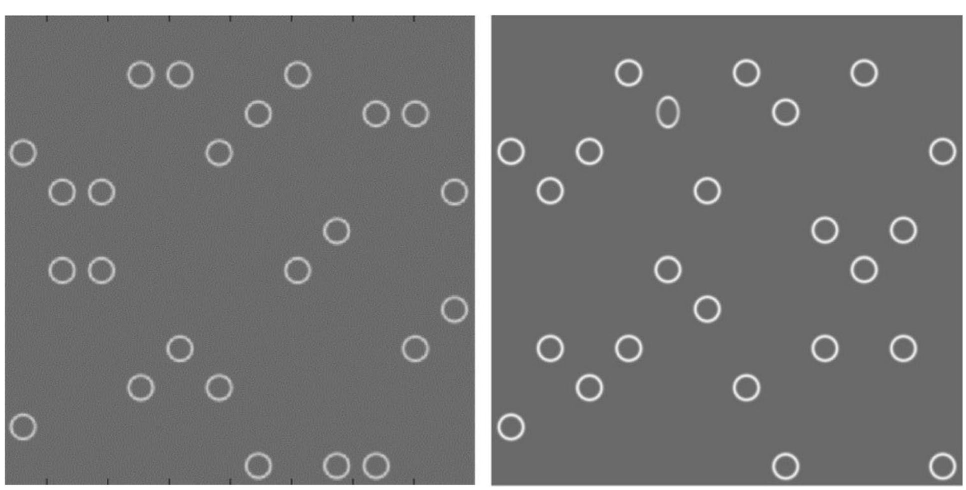

Fig. 1 Display presentations for the feature search task with set size 24. Left figure shows the target-absent condition (no ellipse), and the right figure shows the target-present (ellipse) condition, in which an ellipse is present within the circular distractors

that the participant had feedback throughout the recording session. For the test trials there were six possible combinations of set size (4, 16, or 24) and target (present or absent) which allowed for 12 responses on average (range 8–15) per possible combination of set size and target (72 trials/6 possible combinations =12). Given the random number of total presentations of each test condition which ranged from 8 to 15, we included only the first eight correct reaction times for each combination of the test trails. Test trials were excluded if the reaction time was greater than 10 seconds. The accuracy (percentage correct) was equal to 8 divided by the number of trial combinations required to obtain the eight correct responses. (An accuracy of 83% would equate to 10 correct from 12 trials.) If the accuracy was less than or equal to 50% (i.e., less than or equal to chance) then this observation was excluded. In total six observations were excluded from the vision impaired group for failing to obtain an accuracy of greater than 50%.

Statistical modelling

Reaction time and accuracy data were analyzed separately, and the variables considered were group (G; c = control, I = impaired), gender (g; m = male, f = female), set size (S; 4, 16, and 24), target (T; ab = absent, p = present), nystagmus (n), and age (a). The full model analyzed for each variable was DV ~ G × S × T + n + a + g; such that 'DV' stands for either reaction times or accuracy data, '*' stands for interactions and main effects and '+' stands for main effects only.

The statistical modelling consisted of (1) determining the importance of the variables via the Boruta (Kursa & Rudnicki, 2010) and the One Rule (Holte, 1993) algorithms; (2) examining the full model via quantile (Waldmann, 2018), robust (Yu & Yao, 2017), and distributional (Kneib et al., 2021) regression models (this step is grounded in a multiverse analytical approach, as described by Steegen et al., 2016, akin to ensemble methods in machine learning, and allows rectifying Step 1 and finding patterns in data); (3) proposing an explainable reduced model based on the patterns found in Step 2 and examining that model through the regression techniques used in Step 2 (additionally, if suitable, a factorial design version of the explainable model was analyzed via ANOVA-type statistic (Brunner et al., 2017; otherwise the model was analyzed via quantile regression); and (4) generating a distributional regression tree as described by Schlosser et al. (2019).

Different from traditional regression trees, distributional regression trees enable to fit continuous and discrete variables' location, scale, and shape parameters with probability distributions other than those in the exponential family (which includes the Normal distribution). Each distribution's parameter is fitted with the same covariates and the first split occurs based on the parameter that shows the largest effect (no smoother can be applied to numeric covariates; i.e., the tree is based on proper distributional differences). Distributional trees detect split points which correspond to detecting abrupt changes precisely, but this might be a problem when the underlying effect is smooth. If this is the case (i.e., if the underlying effect is smooth), it is usually a good idea to build not only a single distributional regression tree but an ensemble of trees, i.e., a distributional forest. Additionally, the results of regression trees are interpretable and enable predictions and decisions relating to the data at hand (see Chapter 8 in James et al., 2021, and Section 5.4 in Molnar, 2022). Thus, the goal of the statistical modelling in this study is to propose a regression tree that preserves a small set of key variables and that ultimately facilitates a parsimonious interpretation.

As the name indicates, distributional regression trees are dependent on GAMLSS regression. GAMLSS is one of the few existing distributional approaches able to overcome focusing on average or mean differences (Kneib, 2013; Kneib et al., 2021). More specifically, GAMLSS is a semiparametric approach for statistical learning and modelling that allows dealing with random effects and nonlinear covariates via additive terms (e.g., smoothers; this is the 'semi-', or nonparametric, part of GAMLSS) and fitting the dependent variable with any probability distribution (this is the 'parametric' part of GAMLSS). While using smoothers for numeric covariates is characteristic of generalized additive models (Hastie & Tibshirani, 1986), GAMLSS offers that option in addition to enabling to inspect the effect of covariates on all the parameters of the dependent variable. Thus, while a traditional linear regression assumes the dependent variable follows a Normal distribution and allows to determine mean differences or effects, GAMLSS would allow determining mean effects and effects on the data's variability. This is so, given that the Normal distribution has the parameters mu and sigma that represent the data's location and scale (in the case of the Normal distribution there is only one shape as its skewness and excess kurtosis are always 0). In other words, provided the Normal distribution is a good fit to the response variable, only GAMLSS allows to examine if there are effects of the covariates on the data's location and scale.

Appropriate nonparametric tests were used as required to compare demographic data. Association between reaction time and visual acuity were evaluated using Kendall tau statistic and the percentage bend correlation estimator (Wilcox, 1994). A p value of <.05 was taken as significant.

All data, R code, statistical outputs, and MATLAB stimulus code are available (https://figshare.com/projects/Feature_visual_search_in_children_with_a_visual_impairment_A_multiverse_analysis_approach/132971).

Results

Reaction times

The final set of variables arrived at from Steps 1–3 consisted of G, S, T, and g. The ANOVA-type statistic (ATS) was used given that the factorial design version of the explainable model enabled the variable 'gender' to interact with the other variables and because factorial designs are interpretable. The ATS suggested main effects of all factors, G = $F(1, 305) = 210.2$, $p < .0001$, S = $F(1.99, 305) = 136.9$, $p < .0001$, T = $F(1, 305) = 128.6$, $p < .0001$, and g = $F(1, 305) = 18.2$, $p < .0001$, and two significant two-way interactions, T × S = $F(1.99, 305) = 8.51$, $p < .001$, and G × g = $F(1, 305) = 6.71$, $p = .01$. All other interactions and main effects were nonsignificant ($p > .11$).

Figure 2 shows the distributional regression tree, with the upper 'top' branches having greater significance than the lower 'bottom' branches based on the differences in their location, scale, and shape. Thus, the first node is the starting point for decisions is between the distributions of Set Size 4 and Set Size 16, 24. For the case of Set Size 4, the distributions differ between group (Node 2) but only in the case of controls is there a significant difference between the distributions of reaction times in the target-absent and target-present condition (Node 3). The distributions of the (conditional) reaction time data are shown as Nodes 4–6.

There was a significant ($p < .001$) positive correlation between reaction time and binocular visual acuity (Kendall's tau = .34 and percentage bend correlation = .44).

Accuracy

The final set of variables arrived at from Steps 1 to 3 consisted of S, T, and a. An ANOVA-type statistic was not suitable to this data given that 'age' is not a categorical variable and rendering it into a categorical one, although possible, is not recommended (see Gelman & Park, 2009).

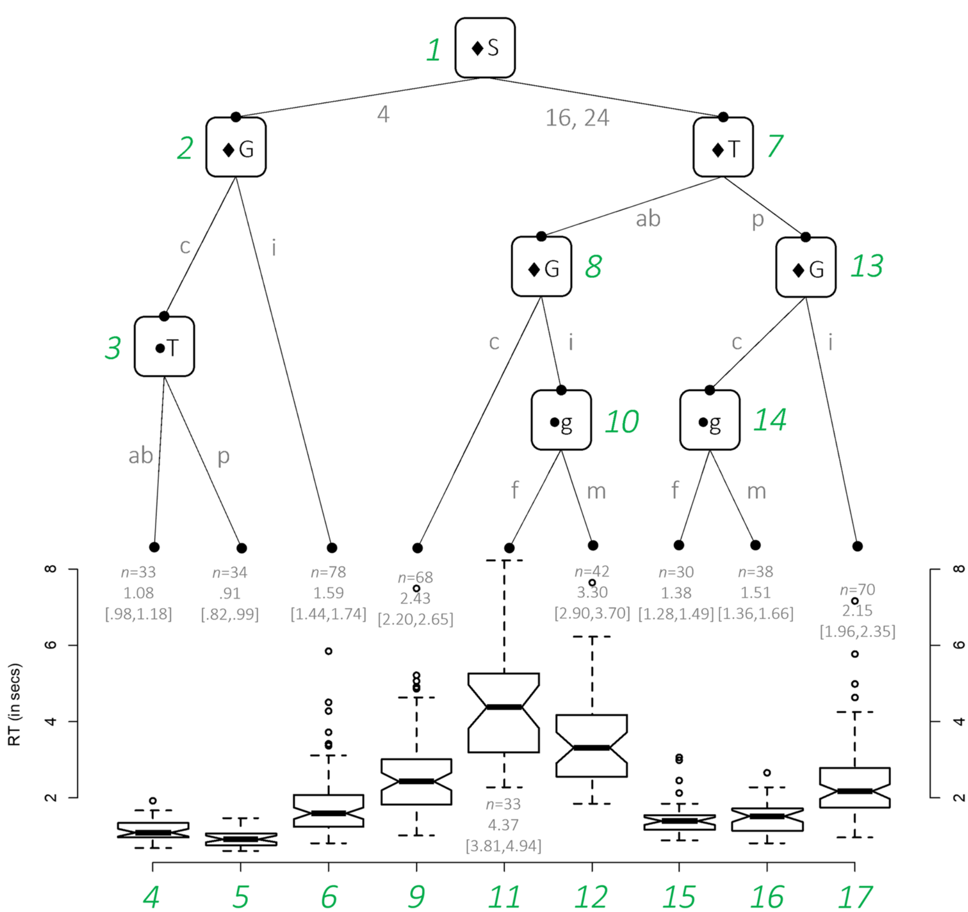

Fig. 2 Distributional regression tree for reaction times (RTs) according to the factors group (G; c = control, i = impaired), gender (g; m = male, f = female), set size (S; 4, 16, and 24), and target (T; ab = absent, p = present). The data were modelled with an ExGaussian distribution. ● $p < .05$ and ◆ $p < .001$. The numbers in green show the order of the nodes. The number of observations, the median and approximate 95% CI around the median are reported, respectively, in the format n = xx, xx [xx, xx]. (Colour figure online)

A linear quantile model was thus used. This model suggested one two-way (T × S = β: −.10, p = .02) and one three-way significant interactions (T × S × a = β: 6.3e^{-03}, p = .03) only. Figure 3 represents the way these variables interact.

The distributional regression tree indicates that the most significant difference (Node 1) was between accuracy scores between Set Size 4 and Set Sizes 16, 24 (p = .002). Within Set Sizes 16, 24 the next most significant difference between the distributions was for the target-present or target-absent condition (p = .005). The next most significant difference between the distributions that influenced accuracy was age, with the participants aged under 14 being significantly less accurate (p = .03). There were no significant overall differences between groups for accuracy in either condition in a linear quantile model that considered main effects of and interactions among G, S, and T while controlling for 'age' (p = .73).

Discussion

This study adopted a different statistical approach, based on comparisons of the location, shape, and scale of data's distributions to analyze the most significant differences between reaction times and accuracy in school aged individuals with a vision impairment and typically sighted children. For reaction times, based on Fig. 2, the main finding was that there were significant differences in search performance based on either Set Size 4 or on Set Sizes 16 and 24 ($p < .001$) at Node 1. This observation implies that the group's performance depended upon set size above other factors. Following to Node 2, there is a group difference for reaction times at this set size ($p < .001$) with the vision impairment group having a median reaction time of 1.59 ms for target absent or present. However, for the control group there was a significant difference for reaction time ($p < .05$) between target present (0.91 ms) or absent (1.08 ms) at Set Size 4

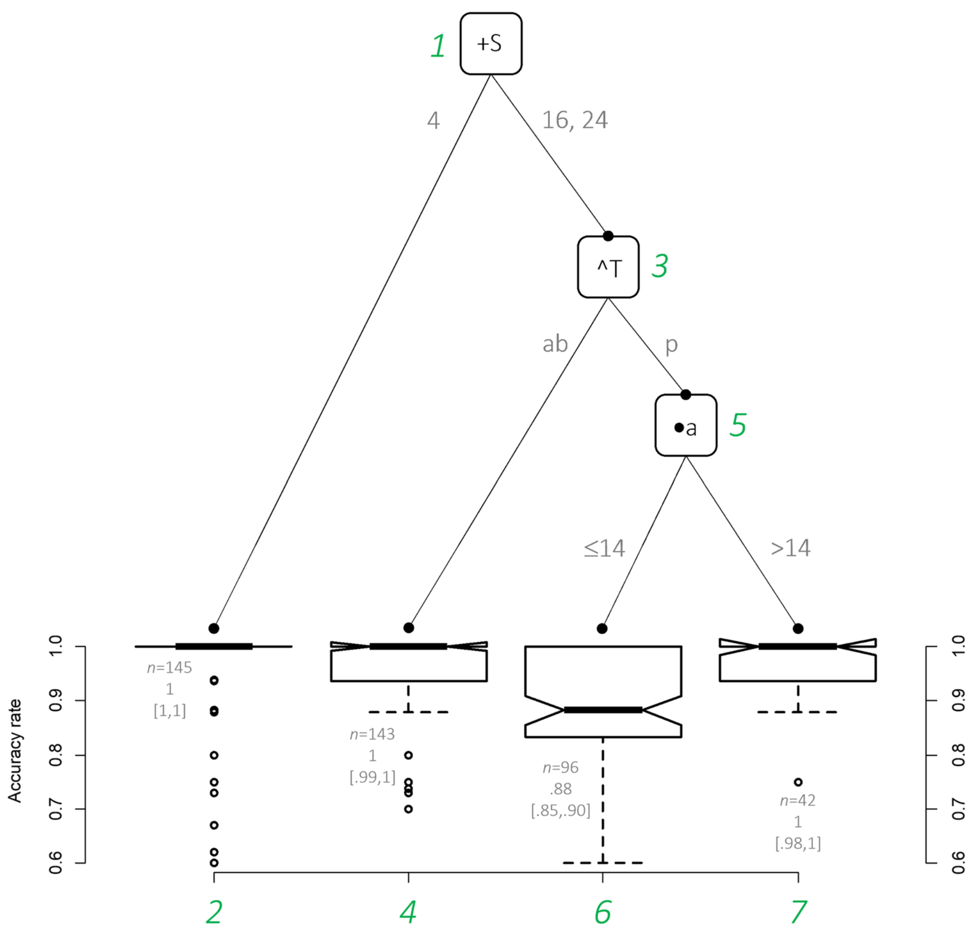

Fig. 3 Distributional regression tree for accuracy rates according to the factors age, set size (S; 4, 16, and 24), and target (T; ab = absent, p = present). The data were modelled with a generalized beta Type 1 distribution. ●$p < .05$, ^p = .005, and +p = .002. The numbers in green show the order of the nodes. The number of observations, the median and approximate 95% CI around the median are reported, respectively, in the format n = xx, xx [xx, xx]. (Colour figure online)

(Node 3), which was not significant for the vision impairment group. These differences at Set Size 4 suggest that the search time for target absent or present are not different for the vision impairment group implying a serial search strategy for target-present and target-absent conditions with equivalent search times (Nodes 4–6). In contrast, the control group had a significantly shorter search time as expected for the target-present condition as they would halt the search once the target was located.

For Set Sizes 16 and 24, the observations were different in some respects. Whilst there was a significant difference based on target present or absent ($p < .001$) at Node 7, this is consistent with standard findings in feature search based on serial and parallel search models (Duncan & Humphreys, 1989; Treisman & Gelade, 1980). For the target-absent condition at Set Sizes 16 and 24 (Node 8), the control group were significantly faster ($p < .001$) than the vision-impairment group, with a median search time of 2.43 seconds (Node 9). The unexpected observation was that for sex (Node 10) the female vision impaired group were significantly ($p < .05$) slower 4.37 seconds (Node 11) than males 3.10 seconds (Node 12). These findings suggest that vision-impaired females take longer in their approach to a target-absent search strategy, and perhaps taking longer to confirm that the target ellipse is absent from the circular distractors before committing to a response.

For the target-present condition at Set Sizes 16 and 24, there were significant group differences, with the vision-impairment group performing slower overall (2.15 seconds Node 17) than the control group ($p < .001$; Node 13). However, in contrast to the target-absent condition, where vision-impaired females were slower, in the target-present condition, it was the control males (Node 14) that were significantly ($p < .05$) slower (1.51 seconds) than their female (1.38 seconds) counterparts (Nodes 15 and 16). This observation is unlikely to be due to differences in hemispheric volume, with males performing poorly in a feature-based task when the target is in the left hemifield compared with the right (English et al., 2021) because target and distractors were of equal number in each hemifield for this task. This observation may be that in this cohort the male subjects took longer to decide on whether the ellipse was present or not.

The exact reason as to why there were sex differences in reaction time depending on Set Sizes 16 and 24, for the control (target-present males slower [Node 14]) or vision impairment (target-absent females slower [Node 10]) is not clear, given the target distractor arrays were symmetrical about the midline. The observation may indicate some differences in the cognitive style of the participants based on their ability and confidence to decide whether a target was present or absent. We did not adjust for the individual's discrimination thresholds to detect a circle from the ellipse or estimate their critical spacing and the possible effects of crowding on search performance which was a limitation of the study Constable et al. (2010). These factors may have also contributed to sex differences observed. Nonetheless, the application of the distributional regression tree approach to reaction times provides a hierarchical view of the main factors that differentiate the groups based on set size (Node 1) as the most important to differentiate the reaction times. As expected, there was a significant ($p < .001$) positive correlation (percentage bend correlation = 0.44) between reaction time and visual acuity, with reduced visual acuity resulting in longer search times in adults and children as previously reported (Huurneman et al., 2014; Kuyk et al., 2005; Luo et al., 2012).

With respect to accuracy (Fig. 3), we found that there was a significant difference based on set sizes (4 compared with 16 and 24) at Node 1 ($p = .002$). This finding is as expected, with search accuracy decreasing with the set size and number of distractors. However, there were no significant differences between groups in any of the nodes for accuracy indicating that the control and vision impairment groups performed with equal accuracy across combinations of set size and target absent or present. Only at Node 3 for Set Sizes 16 and 24, there was a significant difference between the overall accuracy for the target-present compared with the target-absent condition ($p = .005$) which is consistent with feature search findings with greater errors when the target is present than when it is absent (Duncan & Humphreys, 1989; Treisman & Gelade, 1980).

The interesting observation occurred at Node 5 in the target-present condition for Set Sizes 16 and 24, where participants less than 14 years of age were significantly less accurate (88%) ($p < .05$) than those over 14 years of age (98%). These age differences may be related to differences in the rate of maturation of visual search networks that have been identified using imaging studies in children ages 7 to 16 (Lidzba et al., 2013). Gil-Gómez de Liaño et al. (2020) found a similar result for accuracy in typically developing children with accuracy reaching a plateau level at approximately age 9–10 for a complex search task using real-life objects. Thus, for accuracy analysis, the hierarchical structure of the regression tree gives an overview of the most significant factors affecting accuracy, which was set size followed by target present or absent, then age. With respect to these populations, the inference is that a vision impairment does not significantly impact search accuracy compared with school age matched individuals.

The methodological approach proposed herein is based on the GAMLSS framework. GAMLSS has been adopted for growth charts (e.g., Borghi et al., 2006), brain charts (e.g., Bethlehem et al., 2022), and reference curves (see the Introduction; see also Durán et al., 2016). More recently, GAMLSS has been featured to model psychological (Campitelli et al., 2017) and educational (Wiedermann et al., 2022) data. As mentioned above, GAMLSS overcomes limitations of other techniques, such as ordinary linear regression and generalized linear regression, by taking care of nonlinear covariates and relating the conditional mean of the response to explanatory variables through distributions other than those of the Exponential family. GAMLSS is also an improvement on generalized additive models by allowing to model all the parameters of the response variable. The novel attribute that only GAMLSS can offer is to assess the effects of covariates on all the parameters of the statistical distribution that best fits the response variable.

While existing decision trees can only produce one flowchart-like structure for a specific model, GAMLSS-based decision trees can have different structures. This is so because the flowchart-like structure of the tree will change depending on the distribution used to model the dependent variable in the GAMLSS model. In the present study, the reaction times were modelled via the Ex-Gaussian distribution as this is the most common distribution used to fit such type of data (Marmolejo-Ramos et al., 2015). However, reaction time data from a potential replication study could be better fitted with other candidate distributions such as, just to mention a few, the Gamma, Ex-Wald, or Birnbaum–Saunders. In those cases, the decision trees would be different, but they will likely highlight common patterns in the data.

In conclusion, GAMLSS may provide additional information to studies using visual search in addition to standard measures of set-size slopes and intercepts that are traditionally used in visual search tasks to evaluate serial or parallel search strategies (Kristjánsson, 2015; Wolfe, 2016). For example, in this simple case, the factors of age and gender were important in identifying search performance differences between children with and without a vison impairment at specific set sizes and in cases of target present or absent. Similarly in search studies involving participants where neurodevelopmental or neurodegenerative conditions may impact search ability and performance such as autism spectrum disorder (Almeida et al., 2010; Constable et al., 2010, 2020; Gregory & Plaisted-Grant, 2016; O'Riordan, 2004), attention-deficit/hyperactivity disorder (Seernani et al., 2021), dementia (Douglass et al., 2019), and Parkinson's disease (Ranchet et al., 2020). In such case-control studies, the application of GAMLSS with distributional regression trees to determine the most to least significant factors affecting reaction time and accuracy may yield new insights into the differences between case and control groups.

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Code availability R code for statistical modelling and MATLAB stimulus code are available online (https://figshare.com/projects/Feature_visual_search_in_children_with_a_visual_impairment_A_multiverse_analysis_approach/132971).

Authors' contributions L. L, P.C., and M.P-S conceived the study and collected all data. P.C wrote the first draft of the manuscript. F.M-R performed the statistical analysis. All authors contributed to the final manuscript.

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Data availability The datasets analyzed during the current study are available in the FigShare repository: https://figshare.com/projects/Feature_visual_search_in_children_with_a_visual_impairment_A_multiverse_analysis_approach/132971

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki and was approved by the Women's and Children's Health Network, Human Research and Ethics Committee (HREC/19/WCHN/177), The South Australian Department of Education (2019-0047).

Consent to participate Written informed consent was obtained from the parent/guardian of the participant prior to taking part in this study.

Consent for publication Not applicable.

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Appendix 2: Conference Presentations

South Pacific Educators of Vision Impairment (SPEVI)

Loh L. Functional vision assessments: providing clarity for teachers and educators. SPEVI; 12-15th January 2020. Adelaide, South Australia.

Orthoptics Australia Annual Conference

Loh L. Visual acuity and reading ability - time for change in the classification of childhood vision impairment**.** 77th Orthoptics Australia Virtual Annual Conference; 26-Feb-22 to 27-Feb-22.

VISCON 2023

Loh L. The development of a functionally representative framework to assess and support students with a vision impairment through education. VISCON, Next Sense, Macquarie University, Sydney, NSW. 19th and 20th October 2023.

Appendix 3: Poster Presentations

Royal Australian and New Zealand College of Ophthalmologists (RANZCO)

Loh L, Prem-Sentil M, Loh RSK, Constable PA. Visual acuity and reading ability - time for change in the classification of childhood vision impairment. RANZCO Annual Congress. 26th February 1st - March 2022.


RANZCO VIRTUAL 52nd 2022

Australian Vision Research recommended abstract

52nd Annual Scientific Congress 2022

Ms Lynne Loh

RANZCO Poster Program Paediatric ophthalmology

Time for change in the assessment of children with a vision impairment

Prof Stephanie Watson
Chair, Australian Vision Research

AUSTRALIAN VISION RESEARCH
australianvisionresearch.org

Flinders University DocFest: 2-minute thesis 2020

Dialogue:

"Imagine a world where everything is difficult to see.

Imagine after reading one paper you have a headache or are exhausted from visual fatigue. Imagine being surrounded by colleagues at work that can read or perform a task so much faster than you can.
Do your colleagues think you are inadequate for the job you have? – or perhaps you feel inadequate yourself?

Students with a vision impairment are currently categorised and supported within a classroom environment based on the line of letters they read on a vision chart in a clinic.

This measurement gives no valuable information of child's visual ability or performance. In other words – what can they do with the vision they have?

And childhood vision impairment is complex. Different pathologies present different visual abilities, making it incredibly difficult for a teacher to translate that letter line measurement into – can this child see the board? what is the best print size print for them? How long do they need to read a passage of text compared to the rest of the class? What lighting do they need? Is the ability to understand visual information affected? And how long can a child sustain reading before they become tired?

This is where my research comes in…

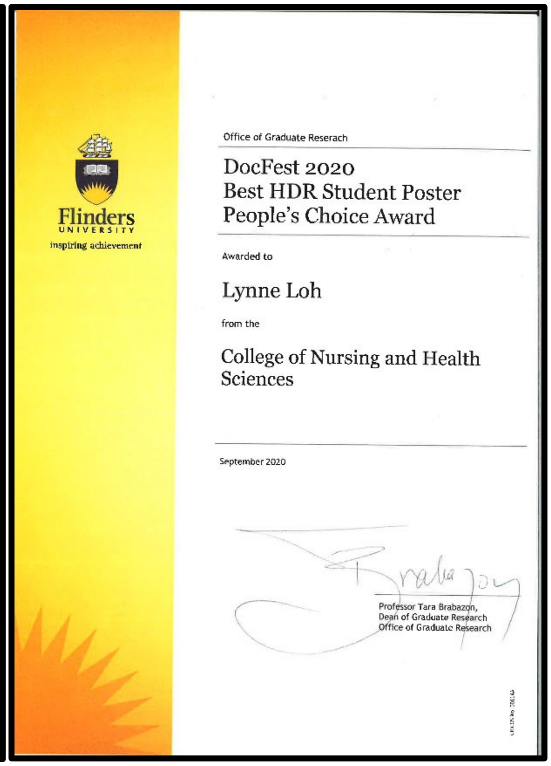
A functional vision assessment looks at all these areas. It finds areas of greatest deficit, helps teachers and parents understand these difficulties and provides specific advice on helping a child to overcome them.

Hermione (not her real name!) has an eye condition that means her vision works better under dim illumination. When I analysed her reading performance, she could read at TWICE the speed when she has white writing on a black background – or reverse polarity.

Harry is classified as blind, and his parents were told he has no usable vision - but he does! Harry just takes significantly longer to process visual information. So now in a quiet room, with some creative strategies – Harry has just started to learn letter shapes and names of colours.

This is just 2 examples - but just as all children are different, so is their visual ability and they all need different strategies to overcome these.

My aim is to build a testing framework and re-categorisation system that can be implemented nationally. Functional classification creates more understanding around visual ability and will allow teachers to provide the best educational experience for all children with a vision impairment – because every child deserves the best education."



Appendix 4: Other Presentations

Functional Vision Assessments. Flinders Ophthalmology Department, Flinders Medical Centre, Bedford Park, South Australia. 17th June 2020.

Improving educational outcomes for students with a vision impairment. South Australian branch of Orthoptists Australia. 12th October 2021.

Improving educational outcomes for students with a vision impairment. Educators of Vision Impairment, Narbethong State Special school, Brisbane, Queensland, Australia. 24th November 2021.

Improving educational outcomes for students with a vision impairment. South Australian School and Services for Vision Impaired. October 2021.

Visual Acuity and Reading Ability. South Australian School for Vision Impaired. 27th July 2022.

Final Thesis Presentation. Flinders Ophthalmology Department, Flinders Medical Centre, Bedford Park, South Australia. 28th June 2023.

Final Thesis Presentation. South Australian School and Services for Vision Impaired, Statewide Support Services and South Australian Department of Education Representatives. Ascot Park, South Australia. 28th August 2023.

Appendix 5: Workshops and teaching

South Australian School and Services for Vision Impairment and Statewide Support Service. Introduction to vision impairment workshop for mainstream educators of students with a vision impairment. 4th March 2020, 6th March 2020, 3rd February 2021, 30th April 2021, 4th August 2021, 1st September 2021, 25th October 2021, 10th November 2021, 14th February 2022, 18th February 2022, 28th February 2022.

South Australian School and Services for Vision Impairment and Statewide Support Service. MNREAD, Reading analysis training. 7th September 2022 and 30th September 2022.

South Australian School and Services for Vision Impairment and Statewide Support Service. Functional Vision Assessment training. 17th May 2023.

Appendix 6: Feedback from Statewide support teachers on assessments.

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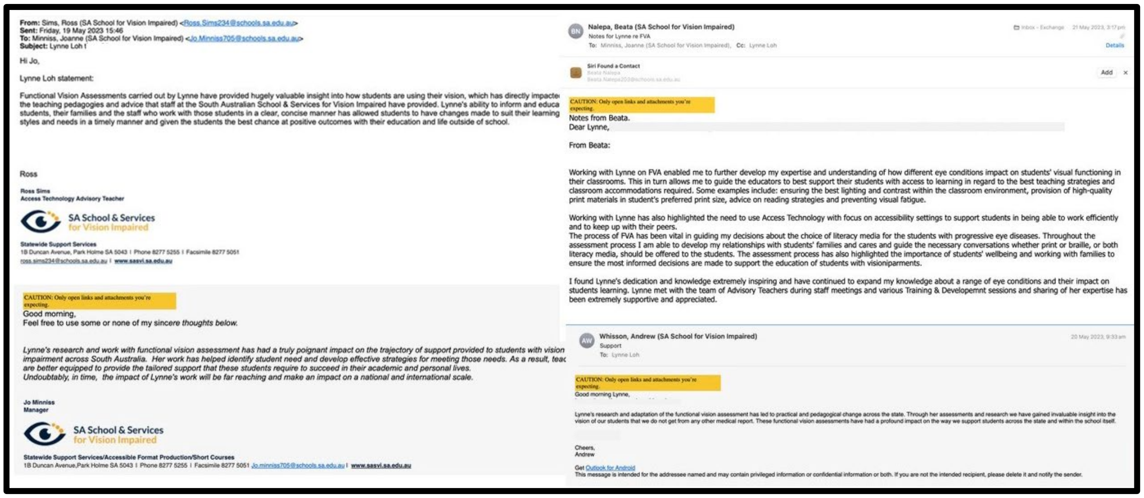

From: Sims, Ross (SA School for Vision Impaired) <Ross.Sims234@schools.sa.edu.au>
Sent: Friday, 19 May 2023 15:46
To: Minniss, Joanne (SA School for Vision Impaired) <Jo.Minniss705@schools.sa.edu.au>
Subject: Lynne Loh t

Hi Jo,

Lynne Loh statement:

Functional Vision Assessments carried out by Lynne have provided hugely valuable insight into how students are using their vision, which has directly impacte the teaching pedagogies and advice that staff at the South Australian School & Services for Vision Impaired have provided. Lynne's ability to inform and educa students, their families and the staff who work with those students in a clear, concise manner has allowed students to have changes made to suit their learning styles and needs in a timely manner and given the students the best chance at positive outcomes with their education and life outside of school.

Ross

Ross Sims
Access Technology Advisory Teacher

SA School & Services for Vision Impaired

Statewide Support Services
18 Duncan Avenue, Park Holme SA 5043 | Phone 8277 5255 | Facsimile 8277 5051
ross.sims234@schools.sa.edu.au | www.sasvi.sa.edu.au

CAUTION: Only open links and attachments you're expecting.
Good morning,
Feel free to use some or none of my sincere thoughts below.

Lynne's research and work with functional vision assessment has had a truly poignant impact on the trajectory of support provided to students with vision impairment across South Australia. Her work has helped identify student need and develop effective strategies for meeting those needs. As a result, teac are better equipped to provide the tailored support that these students require to succeed in their academic and personal lives.
Undoubtably, in time, the impact of Lynne's work will be far reaching and make an impact on a national and international scale.

Jo Minniss
Manager

SA School & Services for Vision Impaired

Statewide Support Services/Accessible Format Production/Short Courses
18 Duncan Avenue,Park Holme SA 5043 | Phone 8277 5255 | Facsimile 8277 5051 Jo.minniss705@schools.sa.edu.au | www.sasvi.sa.edu.au

Nalepa, Beata (SA School for Vision Impaired)
Notes for Lynne re FVA
To: Minniss, Joanne (SA School for Vision Impaired), Cc: Lynne Loh
Inbox - Exchange 21 May 2023, 3:17 pm
Details

Siri Found a Contact
Add

CAUTION: Only open links and attachments you're expecting.
Notes from Beata.
Dear Lynne,

From Beata:

Working with Lynne on FVA enabled me to further develop my expertise and understanding of how different eye conditions impact on students' visual functioning in their classrooms. This in turn allows me to guide the educators to best support their students with access to learning in regard to the best teaching strategies and classroom accommodations required. Some examples include: ensuring the best lighting and contrast within the classroom environment, provision of high-quality print materials in student's preferred print size, advice on reading strategies and preventing visual fatigue.

Working with Lynne has also highlighted the need to use Access Technology with focus on accessibility settings to support students in being able to work efficiently and to keep up with their peers.
The process of FVA has been vital in guiding my decisions about the choice of literacy media for the students with progressive eye diseases. Throughout the assessment process I am able to develop my relationships with students' families and cares and guide the necessary conversations whether print or braille, or both literacy media, should be offered to the students. The assessment process has also highlighted the importance of students' wellbeing and working with families to ensure the most informed decisions are made to support the education of students with visioniparments.

I found Lynne's dedication and knowledge extremely inspiring and have continued to expand my knowledge about a range of eye conditions and their impact on students learning. Lynne met with the team of Advisory Teachers during staff meetings and various Training & Developemnt sessions and sharing of her expertise has been extremely supportive and appreciated.

Whisson, Andrew (SA School for Vision Impaired)
Support
To: Lynne Loh
20 May 2023, 9:33 am

CAUTION: Only open links and attachments you're expecting.
Good morning Lynne,

Lynne's research and adaptation of the functional vision assessment has led to practical and pedagogical change across the state. Through her assessments and research we have gained invaluable insight into the vision of our students that we do not get from any other medical report. These functional vision assessments have had a profound impact on the way we support students across the state and within the school itself.

Cheers,
Andrew

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This message is intended for the addressee named and may contain privileged information or confidential information or both. If you are not the intended recipient, please delete it and notify the sender.

"Lynne's research and work with functional vision assessment has had a truly poignant impact on the trajectory of support provided to students with vision impairment across South Australia. Her work has helped identify student needs and develop effective strategies for meeting those needs. As a result, teachers are better equipped to provide the tailored support that these students require to succeed in their academic and personal lives.
Undoubtedly, in time, the impact of Lynne's work will be far-reaching and make an impact on a national and international scale."

Jo Minnis, Manager, SA School & Services for Vision Impaired

"I have had the pleasure of working with Lynne Loh in my role as an advisory teacher at the SA School for Vision Impaired (SASVI). During my time in this role Lynne has conducted multiple functional vision assessments (FVAs) with my students. While I pride myself on understanding and working with my students' vision impairments, I have learnt something from every one of Lynne's FVAs. Her in-depth analysis of the students' vision goes far deeper than the basic visual acuities we are given from ophthalmologists and has real-world applications for us as educators and for the families of our students. In 2020 I was lucky enough to have Lynne perform an FVA on a student with retinal dystrophy. While I was aware that anecdotally this child's vision had deteriorated the latest ophthalmology report stated that there was no change to his visual acuity. Lynne's functional vision report provided the school, family, and me with a detailed understanding of his condition and why we were seeing changes while the acuity seemed to have stayed stable. This has led to a dramatic change in our approach and has seen the introduction of new technology for the student to ensure he has access to the curriculum. This one report has allowed us to get ahead of the deterioration in the student's vision and put in place key programs like 'Fusion', knowing that he could progress to a JAWS user. If it wasn't for this report we could have assumed the change was behavioural or caused by visual fatigue from extracurricular activities.

Lynne's research and adaptation of the functional vision assessment has led to practical and pedagogical change across the state. Through her assessments and research, we have gained invaluable insight into the vision of our students that we do not get from any other medical report. These functional vision assessments have had a profound impact on the way we support students across the state and within the school itself.

Lynne's knowledge and work is invaluable to what we do and is constantly guiding our practice."

Andrew Whisson, Advisory Teacher, SA School and Services for Vision Impaired

"I am the PE specialist at the SA School for Vision Impaired (SASVI). My role in our service is to support students with vision impairment, both at SASVI and in school around the state, to access the mainstream PE curriculum and take part in blind sports or mainstream sports programs. Understanding the student's vision beyond their visual acuity is vital to my role as there are so many other variables in PE. Lynne Loh's functional vision assessments (FVAs) allow us to understand the student's depth perception, photophobia, required contrast, field of view and the likelihood of further vision deterioration. This understanding allows for a much more precise adaptation of rules and equipment to allow accessibility of sport and PE instruction.

The FVA's being produced by Lynne allow us to see why a student with 6/26 vision may be tracking a ball in a similar manner to someone with 6/60 vision. Why a student with retinal dystrophy may move from 6/60 in ideal conditions to 6/120 or worse in sunlight. Her work has highlighted that there is a better way for athletes to be classified for official competitions, one that takes into account their functional vision not just their acuity. This alone will allow access to competitive sport for so many more athletes that struggle because of their functional vision. Seeing the work that Lynne has produced is incredibly exciting for this field, and I am waiting eagerly to see the next step."

Andrew Whisson, Health and Physical Education Teacher,

SA School and Services for Vision Impaired

"Functional Vision Assessments carried out by Lynne have provided hugely valuable insight into how students are using their vision, which has directly impacted the teaching pedagogies and advice that staff at the South Australian School & Services for Vision Impaired have provided. Lynne's ability to inform and educate students, their families and the staff who work with those students in a clear, concise manner has allowed students to have changes made to suit their learning styles and needs in a timely manner and given the students the best chance at positive outcomes with their education and life outside of school."

Ross Sims, Access Technology Advisory Teacher,

SA School and Services for Vision Impaired

"Lynne's functional vision assessment provided me and school staff with targeted, individualised direction on how to best modify and make adjustments to ensure the student was using the full potential of their limited vision to access and thrive academically. Whilst as VI advisory teachers we have a range of general strategies, modifications and adjustments that we are able to recommend to students and teachers, the FVA provided more detailed and effective strategies specifically meeting the needs of the individual student and their unique needs and requirements."

Sandra Partridge, Advisory Teacher, SA School and Services for Vision Impaired

"Working with Lynne on FVA enabled me to further develop my expertise and understanding of how different eye conditions impact on students' visual functioning in their classrooms. This in turn allows me to guide the educators to best support their students with access to learning in regard to the best teaching strategies and classroom accommodations required. Some examples include: ensuring the best lighting and contrast within the classroom environment, provision of high-quality print materials in student's preferred print size, advice on reading strategies and preventing visual fatigue.

Working with Lynne has also highlighted the need to use Access Technology with focus on accessibility settings to support students in being able to work efficiently and to keep up with their peers.

The process of FVA has been vital in guiding my decisions about the choice of literacy media for the students with progressive eye diseases. Throughout the assessment process, I am able to develop my relationships with students' families and cares and guide the necessary conversations whether print or braille, or both literacy media, should be offered to the students. The assessment process has also highlighted the importance of students' wellbeing and working with families to ensure the most informed decisions are made to support the education of students with vision impairments.

I found Lynne's dedication and knowledge extremely inspiring and have continued to expand my knowledge about a range of eye conditions and their impact on students' learning. Lynne met with the team of Advisory Teachers during staff meetings and various Training & Development sessions and sharing of her expertise has been extremely supportive and appreciated."

Beata Nalepa, Advisory Teacher, SA School and Services for Vision Impaired

"These assessments have improved student learning in many ways, including:

increasing reading speed and efficiency by using reverse polarity – this has been shown in both literacy and numeracy.

knowing the optimum font size to use.

understanding how much longer a child needs to perform a task due to reduced visual processing times."

Judie McGlasson, Teacher, Vision Support Program, Charles Campbell College

"These assessments have changed my entire teaching approach and ensured that my students have the most suitable individualised resources that they need at school, and optimal environmental conditions to learn."

Casandra Whisson, Teacher, SA School and Services for Vision Impaired

Government of South Australia | Health
Women's and Children's Health Network

Women's & Children's Hospital

Research Secretariat
Women's and Children's Health Network
2nd floor
Samuel Way Building
72 King William Road
NORTH ADELAIDE SA 5006
Tel 08 8161 6521
Tel 08 8161 8175
www.wch.sa.gov.au

17th March 2020

Ms L Loh
Dept of Optometry
School of Nursing and Health Science
Flinders University

Dear Ms Loh

Re: The development of a comprehensive functional video assessment to categorise vision impairment in children. HREC/19/WCHN/177. Ethics expiry date: 31/03/2023.

Lead HREC for the above study for the following institutions/sites:

Flinders University
South Australian School for Vision Impaired

I refer to your email dated 10th March 2020 in which you responded to matters raised by the WCHN Human Research Ethics Committee at its 26th February 2020 meeting. I am pleased to advise that your protocol has been granted full ethics approval and meets the requirements of the *National Statement on Ethical Conduct in Human Research.*

Specifically, the following documents have been noted/approved:

Document	*Version*	*Date*
Covering Letter	1	11 November 2019
Patient Information Sheet/Consent Form: Participant Information Leaflet	3	10 March 2020
Patient Information Sheet/Consent Form: Participant Information Leaflet – Child	2	10 March 2020
Patient Information Sheet/Consent Form: Consent Form	3	10 March 2020
Consent to Contact Form	1	11 February 2020
Questionnaire/s: Visual Ability Questionnaire	1	11 November 2019
Protocol: Project Description	1	11 November 2019
HREA Application: AU/1/24CA310		21 October 2019

This letter constitutes advice on ethical consideration only. You must not commence this research project at a site until you have obtained separate research governance approval from the site concerned. A copy of this letter should be forwarded to all site investigators for submission to the relevant Research Governance Officer.

At the WCHN, or any other SA Health site, separate authorisation from the Chief Executive or delegate of that site must be obtained through a Site Specific Assessment (SSA) request. For information on this process at the WCHN, please contact the WCHN Research Governance Officer, Dr Carmel Murone (telephone 8161 6688, email carmel.murone@sa.gov.au).

I remind you approval is given subject to:
- immediate notification of any serious or unexpected adverse events to participants;
- immediate notification of any unforeseen events that might affect continued ethical acceptability of the project;
- submission of any proposed changes to the original protocol. Changes must be approved by the Committee before they are implemented;
- immediate advice, giving reasons, if the protocol is discontinued before its completion;

•submission of an annual report on the progress of the study, and a final report when it is completed to the WCHN Research Governance Officer. It is your responsibility to provide these reports, without reminder. The proforma for the report may be found on the WCHN Research Governance and Ethics website.

Approval is given for three years only. If the study is more prolonged than this, an extension request should be submitted unless there are significant modifications, in which case a new submission may be required. Please note the expiry date in the title above and include it in any future communications.

The WCHN HREC wishes you every success with your research.

Yours sincerely

TAMARA ZUTLEVICS (DR)
CHAIR
WCHN HUMAN RESEARCH ETHICS COMMITTEE

Government of South Australia
Department for Education

System Performance
31 Flinders Street
Adelaide SA 5000
GPO Box 1152
Adelaide SA 5001
DX 541
Tel. +61 8 8226 1609
Education.ResearchUnit@sa.gov.au
www.education.sa.gov.au

Reference No: 2019-0047

Lynne Loh
Dept of Optometry, College of Nursing and Health Science
Flinders University

Dear Ms Loh,

Your research project *"Vision Impairment"* has been reviewed by a senior officer within the Department.

I am pleased to advise you that your application has been approved, subject to the following conditions:

- That a copy of any final reports, presentations or manuscripts accepted for publication be submitted to the Education.ResearchUnit@sa.gov.au mailbox 30 days prior to their publication.

- That the Department for Education is notified when findings are to be released to other government or non-government agencies or to participating sites.

Please contact Georgia Nelson in the Data Reporting and Analytics directorate for any other matters you may wish to discuss regarding your application (Tel. (08) 8226 1609 or email: Education.ResearchUnit@sa.gov.au).

I wish you well with your research.

Yours sincerely

Ben Temperly
EXECUTIVE DIRECTOR, SYSTEM PERFORMANCE

10 January 2020

Government of South Australia
Department for Education

System Performance
31 Flinders Street
Adelaide SA 5000
GPO Box 1152
Adelaide SA 5001
DX 541
Tel. +61 8 8226 1609
Education.ResearchUnit@sa.gov.au
www.education.sa.gov.au

REFERENCE NO: 2019-0047
RESEARCHER: Lynne Loh
RESEARCH BODY: Flinders University

Dear Principal/Director/Site Manager

The research project titled *"Vision Impairment"* has been reviewed centrally and granted approval for access to Department for Education sites. However, the researcher(s) will still need your agreement to proceed with this research at your site.

The researcher(s) whose names appear below are the only persons permitted to conduct research on your site:

Name	Clearance Type	Expiry Date
Lynne Loh	WWCC SA	29/03/2021
Paul Constable	WWCC SA	12/11/2021

Please contact Georgia Nelson in the Data Reporting and Analytics directorate for any other matters you may wish to discuss regarding your participation (Tel. (08) 8226 1609 or email: Education.ResearchUnit@sa.gov.au).

Yours sincerely

B.T.

Ben Temperly
EXECUTIVE DIRECTOR, SYSTEM PERFORMANCE

10 January 2020

Caring Futures Institute
Creating better lives through research

CONSENT TO PARTICIPATE IN RESEARCH

I/We..

(First or given names) (last name)

give consent for my/our child to be involved in the research project:

"The Development of a Functional Vision Assessment to categorise Vision Impairment in Children, With Interventions to Support a Child Access the School Curriculum".

I/We acknowledge that the nature and purpose of the research project, especially as far as they affect my/our child, have been fully explained to my satisfaction by:

Lynne Loh

and my/our 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. Functional Vision Assessment of my/our child

3. Provision of comprehensive assessment report, including strategies to assist my/our child's learning within their school environment.

4. Collaboration with support teachers to implement interventions within the classroom.

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 my child's involvement in this research project, and that I may withdraw my/our consent at any stage without affecting my rights or the responsibilities of the researchers in any respect.

Please specify the name of any other relevant person you would like the assessment report sharing with (e.g Childs Ophthalmologist/Eye Specialist)

…..

Signature of Parent: .... Date: …............................

I, **Lynne Loh**, 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 for his/her child to participate.

Signature:.. Date:.........................

Lynne.loh@flinders.edu.au

Flinders UNIVERSITY

Caring Futures Institute
Creating better lives through research

Project Title
The development of a comprehensive functional vision assessment to categorise vision impairment in children. With interventions to support a child access the school curriculum.

Researchers
Lynne Loh (PhD Student), Flinders University
Dr Paul Constable, Flinders University
Dr Mallika Prem Sentil, Flinders University

Introduction

In South Australia, vision impaired children, in Reception to Year 12, are supported through the Education Departments Statewide Support System. A specialist School for Vision Impairment caters for children with a higher degree of vision impairment from reception-year 7. Entry is visual acuity of less than 6/60 on a letter chart (unable to read top letter on a chart) and/or a severe restriction of their visual field. To qualify for statewide support within any school, visual acuity must be less than 6/18 (about halfway down the vision chart).

Visual acuity, although still widely used as a measurement by doctors and support organisations to determine vision ability, is often an inaccurate measure of how vision functions.

A comprehensive functional vision assessment can assess vision from a functional perspective, determine areas where visual ability is affected and provide methods and adaptions to help support a child within the classroom and throughout their education. These adaptions can include recommendations such as print size, lighting requirements and technology that may be required to help them access the curriculum.

The Purpose of this Study
This study aims to look at how your child is impacted within the classroom due to their vision impairment, and provide support mechanisms to help them access the school curriculum
This research aims to investigate whether there is a different and more comprehensive method to measure visual function in vision impaired children.

To provide a support framework, including advice and recommendations, enabling teachers to address these functional challenges from an early age.

Caring Futures Institute

Creating better lives through research

Why you have been asked

This study is looking for participants aged 5-16 who have been diagnosed with a vision impairment.

What will it involve

If you decide you would like your child to participate, they will be required to attend an appointment at either Flinders University Eye Clinic or The South Australian School for Vision Impaired (SASVI).

They will be required to undergo a functional vision assessment to determine how their vision impairment impacts how their eyes function during tasks. These tests will include standard vision tests using charts, some paper-based tasks and undergoing an electroretinogram (ERG). An ERG is a machine that measures how the retina, and the receptors at the back of the eyes that are responsible for capturing vision information, are working. It involves sticking a small plaster on your child's lower lid and your child looking at some flashes of light. None of the tests include eye drops or any contact with your child's eyes.

Your child will also be asked to complete a brief questionnaire asking them about specific areas in school they may have difficulty with due to their eyesight. They can be given help to complete this.

Following your child's assessment, you will be given a report which will outline areas that your child may have difficulty with. Recommendations will be given to you and your child's support teachers to help with these.

The results of the tests will be stored securely and will only be accessible by the research team. Once the information has been collected and a report given to you and your child's support teacher, then any personal information will be removed so that your child cannot be identified from it. All data is securely stored within Flinders University.

Review

This study has been reviewed by the Human Ethics Research Committee of the National Health and Medical Research Council.

It has also been reviewed by the Education Department of South Australia.

If you would like more information, please contact:

Lynne.loh@flinders.edu.au

Flinders University

Caring Futures Institute
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Functional Vision Assessment Report

Student: “student”

DOB:

School:

Year:

Date of Assessment:

Location:

Eye Condition:

Background Information and history

Retinal Dystrophy

The retina is made up of two types of receptors responsible for capturing information, rods and cones. Rods are responsible for night vision and are more sensitive to movement. Cones are responsible for detecting fine detail and colour vision. Dystrophy is a degeneration of the photoreceptors that make up the retina.

“student”’s support teacher mentioned a noticeable deterioration in “student”’s vison over the past year. He is also having more difficulty academically this year.

“student” mentioned that he suffers from night blindness and is unable to see in low illumination. He started long cane training earlier this year in an effort to improve his safety with independent mobility.

“student”’s last Ophthalmology report dated ******, records visual acuities of
R: 6/60, L: 6/95.

Questionnaire Notes

“student” completed the Cardiff Visual Ability Questionnaire for Children on the *******. This questionnaire assesses self-reported visual ability in children with a vision impairment, focusses on important activities in and out of school. It uses items representing activities important to children and is useful to characterise the nature and degree of the difficulties that children and young people with a vision impairment experience in everyday life.

“student” has technology assistance within the classroom to help him access the school curriculum. He did mention that he finds Italian language classes more difficult this year. He has individual teacher support in the classroom - who has recently started scribing for him when he is tired or struggling with work.

Vision/ Ocular Assessment

Visual Acuity FrACT	Right	Left	Binocular	Notes:
Test Distance:	100cm	100cm	100cm	
Crowded	0.95 LogMAR (approx. 6/60)	1.05 LogMAR (approx. 6/60-)	0.77 LogMAR (approx. 6/38)	Requires extensive visual searching and extra time to help identify orientation of Landolt C.
Uncrowded	0.82 LogMAR (approx. 6/60+)	0.98 LogMAR (approx. 6/60)		

Cover Test	Eyes straight. Normal ocular balance.

Ocular Movements	Full ocular movements.
Nystagmus	Small movement, manifest nystagmus. Movement increase on upgaze.
Convergence	Convergence to nose (normal)
Stereopsis	Stereopsis not demonstrated on Frisby stereotest. Good functional depth for near with pen top matching.

Contrast Sensitivity FrACT	50 arcmin: 0.47 LogCS **(significantly reduced)** 100 arcmin 0.75 LogCS **(significantly reduced)** (normal contrast sensitivity for age 13 is approximately 1.93 LogCS (Mäntyjärvi 2005))

Colour Vision	Unable to differentiate Ishihara colour plates. Significant difficulty colour matching pens.

Reading

MNREAD © University of Minnesota	**Normal Polarity 40cm**	**Reverse Polarity 40cm**
Reading acuity (min)	0.73 LogMAR (approx. font size 18)	0.56 LogMAR (approx. font size 12)
Max Reading speed	118 words per minute	119 words per minute
Critical Print Size	1.06 LogMAR (approx. font size 37)	1.06 LogMAR (approx. font size 37)
Accessibility Index	0.34	0.39

Visual Processing

Test of Visual Analysis: TVAS
Completed all plates correctly. Normal result for his age.

Visual Search: Matlab
Notes: significant head movement while scanning. Guessed toward end of test. High error rate. **6 Minutes, 5 seconds** (approximate normal result for his age would be under 2 minutes)

Development Eye Movement Test: DEM
Sheet A (18 font) **20.47 seconds**
Sheet B (18 font) **19.72 seconds**
Sheet C (24 font) **47.31 seconds (normal polarity)** **42.01 seconds (reverse polarity)** **Normal results for his age**

Visual Fields

Confrontation
It was not possible to accurately assess “student”’s visual fields. However, on observation, when performing visual acuity assessment and visual search, “student” demonstrated exaggerated head movements which could be indicative of patchy field loss. Given his visual ability in the dark and his electrophysiology results (see below), a field defect would be likely.

Cone Adaption Test

Room illumination levels:	150 Lux	0 Lux & 50 Lux
Notes	Able to sort red, blue and white accurately.	Unable to see white, blue, or red squares under reduced room illumination. When room illumination was increased slightly – still unable to differentiate some of the blue from white (see photograph in appendix)

Electrophysiology (ERG)

Minimal cone response from either eye – see report in appendix.

Summary and Recommendations

Vision/ Ocular Assessment

Vision

Visual acuity testing at this assessment demonstrated reduced visual acuity. Although he achieved a binocular acuity of 6/38, this was obtained using extra time and "student" had to scan to detect the orientation of the target. His 6/38 acuity means that he is able to differentiate detail at 6 metres, that a person with normal vision would be able to see at 38 metres, however he would need a significantly longer time to differentiate this detail. "student"'s visual acuity was lower with a crowded test compared to an uncrowded one. This is expected, as it is harder for the eye to resolve an image when it surrounded by other detail. Crowded acuity is more representative of what we would be expected to resolve in everyday life.

Nystagmus
Nystagmus is the uncontrolled to and fro movement of the eyes. Often there is gaze position called a "null point", this is where the nystagmus movement is the slowest and vision will be clearest.
"student" demonstrated an increase in nystagmus in upgaze but he did not display any obvious head position that would indicate a null point. "student" is therefore best positioned in a classroom centrally and as close to the front as possible with an unobstructed view of the board to enable him to use his Magnalink.
Nystagmus can also worsen in bright light or glare and can be exacerbated by flickering lights (such as overhead fluorescent tubes). He should therefore be positioned to avoid any direct or indirect glare sources (such as sun shining in the window or reflected from a board). If he uses a white reflective desk, then black card to put over his desk can significantly reduce reflected glare and discomfort.

Depth Perception
"student" is unable to appreciate true depth perception (3D vision). However, functionally he was observed to have no issues with tasks requiring him to judge depth for near. He also used good problem-solving skills and tactile information to help him replace pen lids.

Contrast Sensitivity
Contrast sensitivity is the ability to detect an object against its background. A high contrast task would be black on white, compared to a lower contrast task, for example yellow on white.
"student" has severely reduced contrast sensitivity. He will require bold, clear printed material with minimal clutter and will be unable to see any detail with reduced contrast. When writing on class white boards, the use of higher contrast pens such as black or dark blue are easier for him to see with his Magnalink. Classroom floors should be kept clear of unnecessary clutter as low contrast objects, such as bags and jackets, can cause tripping hazards. His ability to see low contrast objects will be further reduced under lower room illumination, such as a darkened classroom.

Ishihara
"student" demonstrated significant issues with colour discrimination. The use of colour as a descriptor should be avoided and instead use size or placement – for example, use the pen to your right side, rather than use the red pen.

Reading

MNREAD App was developed at the Minnesota Laboratory for Low-Vision Research, University of Minnesota. It was designed to assess aspects of reading such as smallest font size that can be read, critical print size (the smallest font size before reading speed reduces), accessibility to print material and reading speed.
(Legge, Ross et al. 1992, Bailey, Lueck et al. 2000, Virgili, Cordaro et al. 2004, Rice, Birch et al. 2005, Giacomelli, Volpe et al. 2010, Calabrese, Cheong et al. 2016, Calabrese, Owsley et al. 2016, Calabrese, To et al. 2018, Mansfield, Atilgan et al. 2019)

Reading analysis at a comfortable 40cm working distance demonstrated a minimum print size reading ability of 18pt with normal polarity (black on white).
During reading, as we reach the limit of what we can see, reading speed begins to reduce rapidly. Critical Print Size is the largest font size before reading speed begins to decrease. “student”’s critical print size was identified at 37pt with normal polarity. For prolonged reading and to reduce eyestrain at the end of the day then font size of 36-38 would be preferred.

“student” also performed reading analysis with reverse polarity (white writing on a black screen). With reverse polarity “student”’s critical print size was the same and reading speed was similar, but he was able to read smaller font sizes. It would be worthwhile “student” trying reverse polarity with electronic documents, particularly toward the end of the day when he will be experiencing visual fatigue.

Print Accessibility Index is a value that represents access to commonly encountered printed material and is calculated by comparing the results against a person with normal vision - where 0 is no ability to read print and 1 is ability to read all print. “student” has a print accessibility index of 0.34 with normal polarity and 0.39 with reverse polarity. These results indicate “student” has reduced capacity to access commonly printed materials without the use of technology/magnification to help him.

In addition, according to previously published data using the MNREAD charts (Calabrese, Cheong et al. 2016). A 13-year-old child’s average reading speed is 175 words per minute. “student”’s maximum reading speed was 118 words per minute with normal polarity. This indicates that if he is given a passage of text to read, he will require longer to read it, than a normally sighted child.
This information will be particularly relevant to tests or exams.

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Visual Processing

Test of Visual Analysis: TVAS
Visual analysis is one aspect of visual imformation processing, and certain visual processing skills have been shown to have a high correlation with academic performance (Rateau, Laumonier et al. 2003).

Visual Search: Matlab
This test assesses the time to perform a visual search in a visually crowded task. A crowded task is identifying a target in the presence of distractors. Children with a vision impairment show weaker visual search performance than children with normal vision, which can affect reading ability (Huurneman, Cox et al. 2014).

Development Eye Movement Test: DEM
Although originally developed to look at eye movements, this test has been shown to be associated with reading ability and visual processing. Measures are significantly associated with academic performance (Hopkins, Black et al. 2019) and correlate with reading performance and visual processing speed (Ayton, Abel et al. 2009).

When visual information reaches the brain's visual cortex, this information is processed and interpreted. How quickly a scene or detail is interpreted is dependent on the time and ability of the brain to process the images it receives.

"student"'s performance on the Development Eye Movement Test and the Test of Visual Analysis (TVAS) were normal for his age.
The results for Visual Search (Matlab) were significantly reduced compared to a child of the same age with normal vision. "student" visibly struggled to scan the screen and detect a specific target and used exaggerated head movements to aid his scanning. He also became tired toward the end of the test where it appeared he found the task too difficult and began to guess – this was indicated by an increase in error responses toward the end of the test.

This means that if "student" has to detect or pick out detail from complex information, such as maps, graphs, tables or a significant amount of text then it will take him longer to analyse this information. He took approximately three times as long to perform the visual search task compared to a child the same age with normal vision. Finding relevant pieces of information in a large passage of text, table or graph, will be a difficult task for him and he will require significantly longer to do this.
This information will be particularly relevant to tests or exams.

caringfutures@flinders.edu.au
flinders.edu.au/caring-futures
Sturt Road, Bedford Park | South Australia | 5042

Visual Fields

It was not possible to formally assess “student”’s visual fields.
On observation “student” appeared to have patchy field loss and used exaggerated head movements which could be indicative of him scanning to detect detail. Additionally, given his night blindness, which is the degeneration of rod (photoreceptor function) and the results from electrophysiology, which indicate a generalised loss of cone function – then a restricted field would not be unexpected.
This can be formally assessed when “student” is older by his Ophthalmologist.

Cone Adaption Test

In daylight vision we use retinal receptors called cone cells which are responsible for detailed vision and colour. During night vision we use retinal receptors called rods which give less detailed vision, no colour but are more sensitive to movement.
When we enter a darker place, it takes a few seconds before we start to see colours at lower luminance levels. This is called cone adaptation time. In retinal degenerations cone adaption time can be longer than normal.
This test can give useful information on visual adaption to lighting changes.

White, red and blue squares are sorted at a high luminance level, then again at a low luminance level at which the observer can just differentiate the blue and red coloured chips. This test compares the observer adaption time with the child's adaption time.

“student” was unable to see the white, blue, or red squares under reduced room illumination. This demonstrated how significantly impacted “student”’s vision is under reduced illumination. “student” will find it difficult to differentiate even high contrast detail under reduced illumination.
Orientation and mobility, with long cane training, is important for safety and to enable “student”’s long-term independent mobility for the future.

Electrophysiology

When light enters an eye and hits the retinal receptors, this light is converted into an electrical signal which is carried to the visual cortex via the optic nerve. An electroretinogram (ERG) measures the mass electrical response of the retinal receptors to light, using a small electrode (placed) on the lower eyelid. The ERG is performed when the eyes are light adapted and is therefore measuring cone (daytime vision) function.

“student”’s ERG recorded a minimal cone response to light adapted flicker. Due to his night blindness and inability to see detail under reduced room illumination then “student” is also unlikely to have any significant rod function (this can only be measured after 30 minutes dark adaptation). “student” will have a small area of localised cone function in the fovea which enables him to achieve his visual acuity result.

Summary

“student” has significantly impacted visual acuity and visual ability. He has very little functional vision under reduced room illumination and significantly impacted visual function under brighter room conditions.

Retinal dystrophy is often a progressive condition and a change in “student”’s visual performance has already been noted by his school over the past year. It is important that “student” learns the skills which will enable him to independently access the school curriculum - should his vision deteriorate further. Previous published research highlights that the academic gap begins to widen in middle school if vision impaired students are not provided with adequate tools to effectively access the school curriculum independently (Corn, 2002). Enabling vision impaired students with independence skills has also been shown to improve health related quality of life at school (Decarlo et al, 2012).
Providing “student” access to voice text, such as JAWS, would be considered a priority for him over the coming months.

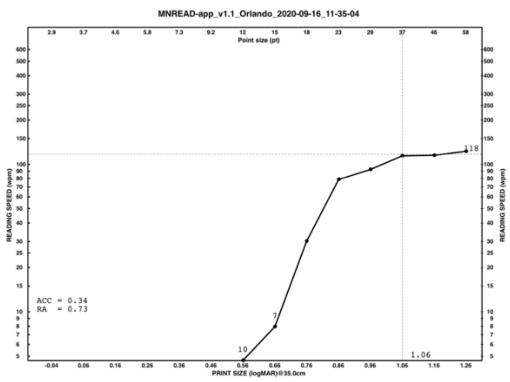
- **Visual acuity 6/38 (crowded) – requires longer to differentiate detail.**
- **Font size 36-38pt.**
- **Severely reduced contrast sensitivity.**
- **Reduced scanning ability – may take up to 3x longer.**
- **Night blindness and generalised loss of cone function.**
- **Unable to differentiate colour.**
- **Requires access to voice text.**

For any questions regarding this report, please contact lynne.loh@flinders.edu.au

APPENDIX

MNREAD

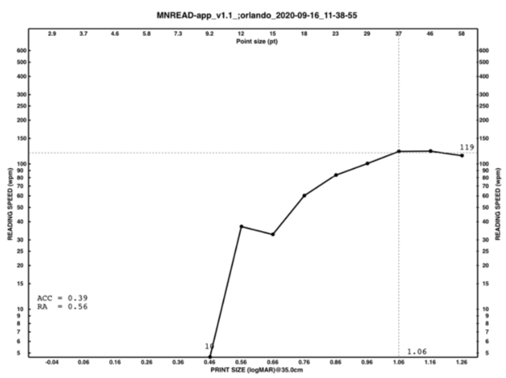
Normal Polarity



SentenceId / PrintSizeAt40cm(logMAR) / PrintSizeAt40cm(M) / CorrectedPrintSize(logMAR) / FontSize(points) / x-height(points) / ReadingTime(seconds) / RawReadingSpeed(wpm) / ErrorCount / CorrectedReadingSpeed(wpm) /

401-en	1.20	6.34	1.26	58.086	26.139	4.89	122.7	0	122.7
402-en	1.10	5.04	1.16	46.140	20.763	5.20	115.4	0	115.4
403-en	1.00	4.00	1.06	36.650	16.492	5.23	114.7	0	114.7
404-en	0.90	3.18	0.96	29.112	13.100	6.49	92.4	0	92.4
405-en	0.80	2.52	0.86	23.125	10.406	7.58	79.1	0	79.1
406-en	0.70	2.00	0.76	18.368	8.266	19.90	30.2	0	30.2
407-en	0.60	1.59	0.66	14.591	6.566	22.70	26.4	7	7.9
408-en	0.50	1.26	0.56	11.590	5.215	6.12	98.1	10	0.0

Reverse Polarity



SentenceId / PrintSizeAt40cm(logMAR) / PrintSizeAt40cm(M) / CorrectedPrintSize(logMAR) / FontSize(points) / x-height(points) / ReadingTime(seconds) / RawReadingSpeed(wpm) / ErrorCount / CorrectedReadingSpeed(wpm) /

501-en	1.20	6.34	1.26	58.086	26.139	5.25	114.2	0	114.2
502-en	1.10	5.04	1.16	46.140	20.763	4.91	122.2	0	122.2
503-en	1.00	4.00	1.06	36.650	16.492	4.93	121.7	0	121.7
504-en	0.90	3.18	0.96	29.112	13.100	5.97	100.5	0	100.5
505-en	0.80	2.52	0.86	23.125	10.406	7.15	83.9	0	83.9
506-en	0.70	2.00	0.76	18.368	8.266	9.94	60.3	0	60.3
507-en	0.60	1.59	0.66	14.591	6.566	18.37	32.7	0	32.7
508-en	0.50	1.26	0.56	11.590	5.215	16.25	36.9	0	36.9
509-en	0.40	1.00	0.46	9.206	4.143	8.50	70.6	10	0.0

ERG

Patient Information

Patient ID: 31
Birthdate: 23 February 2007
Test started: 16 September 2020, 12:22
Report generated: 16 September 2020, 12:27

Device Information

RET*eval*™
Manufacturer: LKC Technologies, Inc.
Serial number: R001051
Firmware version: 2.10.2 Reference data: 2020.07 52e1a6e
Test protocol: DR Assessment
Electrodes: Sensor Strips

Test	Result	Reference Interval
DR Assessment	Not measurable	7.0-19.9

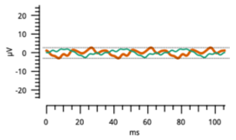
ERG

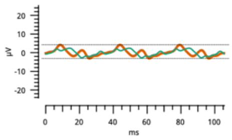
Right Eye	ms	μV
16 Td·s	NM	5.7
32 Td·s	NM	4.6

NM = not measurable

Left Eye	ms	μV
16 Td·s	NM	7.3
32 Td·s	NM	5.2

NM = not measurable



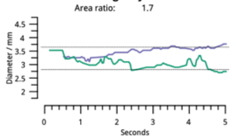


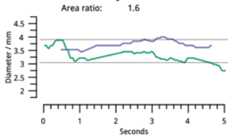
Flash: 16 Td·s, Chromaticity (0.33, 0.33) at 28.3 Hz Background: 0.0 Td
Flash: 32 Td·s, Chromaticity (0.33, 0.33) at 28.3 Hz Background: 0.0 Td

Pupil

Right Eye
Area ratio: 1.7

Left Eye
Area ratio: 1.6

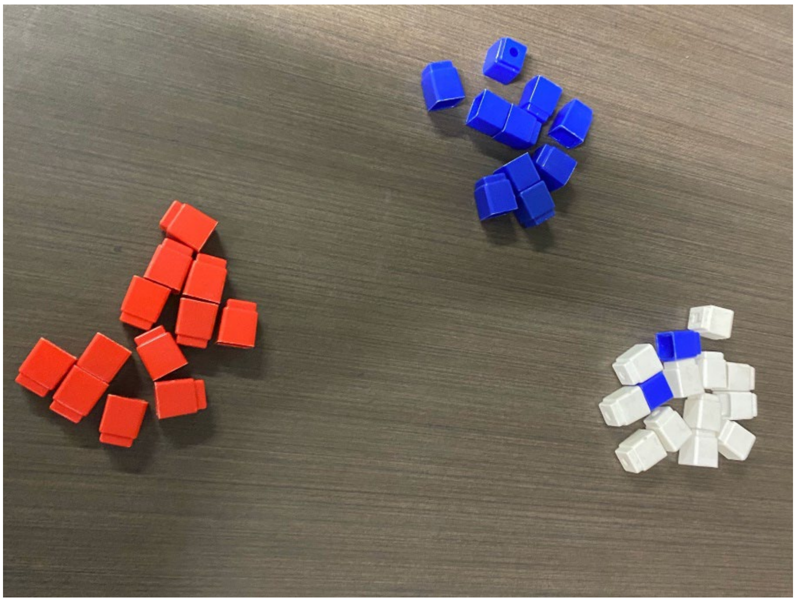




Flash: 4.0 Td·s, Chromaticity (0.33, 0.33) at 28.3 Hz Background: 0.0 Td
Flash: 32 Td·s, Chromaticity (0.33, 0.33) at 28.3 Hz Background: 0.0 Td

caringfutures@flinders.edu.au
flinders.edu.au/caring-futures
Sturt Road, Bedford Park | South Australia | 5042

Cone Adaption Test



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