Reading Additions in Children and Young Adults with Low Vision – Effects on Reading Performance

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Reading is one of the most important activities in most people's life. For children, reading is a window to knowledge, good educational achievement and better job opportunities in the future. Thus reading fluency is a very important factor in the child's education. Children and young adults with low vision usually use a close working distance to gain relative distance magnification. Unlike adults, they have active accommodation. Many studies, however, have shown that children and young adults with low vision have reduced accommodation response compared to the norms of their age. Reading additions (high plus lenses) can correct for this reduction in accommodation and may be an optimum method of prescribing magnification in younger adults with low vision. There have been no studies to verify the best method of prescribing reading additions in young adults with low vision and few studies of their effect on reading performance.

This is the first study to compare different methods to determine reading additions and their effect on reading performance in young adults with low vision. The aims of the present study are 1) to investigate if three different methods to determine reading additions would lead to significantly different dioptric powers 2) to determine which method (if any) would lead to better reading performance. Reading performance was assessed by measuring the maximum reading speed, critical print size (CPS), print size threshold and the area under the reading speed curve.

This was an experimental study involving thirty participants with low vision aged between 8 to 35 years. Participants were recruited from the Low Vision Clinic at the School of Optometry, University of Waterloo, Canadian National Institute for the Blind (CNIB) and the Vision Institute of Canada. All participants underwent a routine clinical examination including

distance visual acuity, near visual acuity, Pelli-Robson contrast sensitivity, unilateral cover test, static retinoscopy, subjective refraction and measurement of the habitual reading distance. A questionnaire was used to determine their usage of any low vision aids, their perceived difficulty with reading and time spent reading. Reading additions were determined by 1) an objective method using Nott dynamic retinoscopy 2) an age-based formula 3) a subjective method based on the participant's response to lenses. Reading tasks and dynamic retinoscopy were conducted at a fixed working distance of 12.5cm. Reading performance was assessed using MNREAD-style reading charts with each of the reading additions and without a reading addition, in a random order. Sentences were arranged in way that no sentence was repeated by the same participant. Participants were timed with a stop watch in order to calculate the reading speed in correct words per minute (CWPM). Reading speeds were plotted against print size to calculate the maximum reading speed, the critical print size, MNREAD threshold and the area under the reading speed curve.

The participant's mean age was 16 (± 6) years. There were equal number of males and females. The mean distance visual acuity of the tested eye ranged from 0.357 to 1.184 logMAR with a mean of 0.797 ± 0.220 logMAR. The near visual acuity ranged between 0.301 to 1.301 logMAR with a mean of 0.80 ± 0.26 logMAR. There were six participants who already had a reading addition. Maximum reading speed ranged between 52 to 257 wpm (165 ± 61 wpm). Critical print size ranged between 0.325 to 1.403 logMAR (0.965 ± 0.279 logMAR).

Repeated measures ANOVA on the whole group showed that there was a significant difference between the reading additions ($p=0.001$). The retinoscopy reading addition power was significantly lower than the age add ($p=0.002$) and the subjective add ($p=0.038$). Repeated measures ANOVA did not show any improvement of any of the reading measures with the

reading additions compared to without the reading addition. A re-analysis was undertaken excluding participants who had normal accommodation at 12.5cm. The results of repeated measures ANOVA showed that there was no significant difference in the dioptric powers obtained by the three methods, although, all reading addition power were significantly greater than zero (t-test <0.0005). There was a significant difference in the area under the reading speed curve (p=0.035), which was greater with the subjective addition than with no reading addition (p=0.048). The MNREAD threshold significantly improved with the age addition compared to no addition (p=0.012).

There was a large variability between the participants in their response to a reading addition. Analysis of individual data showed that some participants showed a clear improvement in reading performance with a reading addition. Other participants did not demonstrate any obvious improvement in reading performance with reading additions. Of those participants who showed an improvement, all but one participant had abnormal accommodation. However, not all participants who did not show an improvement had normal accommodation.

Univariate analysis and forward step-wise linear regression analysis were used to investigate if any improvement in reading performance and the habitual reading performance without a reading addition could be predicted by factors that were measured in the study. These factors included distance visual acuity, near visual acuity, contrast sensitivity, lag of accommodation, age, time spent on reading each day, perceived difficulty of reading regular print and whether or not the participant received training for the usage of his/her low vision aids. Improvement in reading performance could not be predicted by any of these factors. Habitual reading performance without a reading addition was correlated with some factors. Univariate analysis showed that critical print size was associated with MNREAD threshold (r=0.904.

p<0.0005), distance visual acuity (r=0.681, p<0.0005) and contrast sensitivity (r=-0.428, p=0.018) and MNREAD threshold without an addition was associated with the contrast sensitivity (r=-0.431, p=0.017,) and distance visual acuity (r=0.728, p<0.0005). Difficulty of reading correlated with near visual acuity (Spearman correlation coefficient=0.620, p=0.0009), MNREAD threshold (Spearman correlation coefficient=0.450, p=0.02) and maximum reading speed (Spearman correlation coefficient=-0.472, p=0.014). Time spent on reading each day correlated with the area under the reading speed curve (Spearman correlation coefficient=0.659, p=0.0024). The multiple regression analysis showed that MNREAD threshold was best predicted by distance visual acuity (R=0.728, p <0.0005), critical print size could be predicted by distance visual acuity (R=0.681, p <0.0005) and age (R=0.748, p=0.022) and the power of the subjective addition could be predicted by age (R=0.583, p=0.001) and near visual acuity (R=0.680, p=0.028).

There was evidence that a reading addition improved reading performance as measured by the area under the curve and MNREAD (reading acuity) thresholds, but this was not predicted by any visual factor, except that all those who gained improvement had poor accommodation. Therefore, it is recommended that an eye care practitioner should demonstrate a reading addition in a low vision assessment of children and young adults, particularly with patients who have reduced accommodation.

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Dedication

I dedicate this thesis to my parents, thanks for giving me the opportunity to pursue my dreams.

I could not have done this without you!

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Chapter 1: General Introduction

1.1 Low vision

1.1.1 The definition of low vision and blindness

Low vision is generally defined as a vision loss that cannot be corrected with available spectacles, contact lenses, medications or surgeries (Dickinson 1998, Raasch et al. 1997). It negatively affects a person's normal daily living activities (Raasch et al. 1997, Jin & Wong 2008). In children, it may impact the child's education, social life and school activities (Wong et al. 2009). There have been numerous definitions of low vision which vary from country to country and between one study and another (Kartha 2010). Below is a review of some of the common definitions of low vision and blindness that have been used.

According to the WHO, "a person with low vision is one who has impairment of visual functioning even after treatment and/or standard refractive correction, and has a visual acuity of less than 6/18 to light perception, or a visual field less than 10 degrees from the point of fixation, but who uses, or is potentially able to use, vision for the planning and/or execution of a task".(Report of WHO consultation, Bangkok 1992)

In Canada, according to the Canadian National Institute for the Blind (CNIB) (CNIB 2009), visual acuity of less than 6/12 in better-seeing eye, even with corrective lenses. Blindness (a subset of vision loss) is defined as 6/60 or worse in the better-seeing eye, even with corrective lenses, or a visual field of less than 20° degrees in the horizontal plane. There is no specific visual acuity definition to be eligible for the Ontario Assistive Devices Program (ADP). They

defined visual impairment as “Anyone with long-term low vision or blindness that cannot be corrected medically, surgically or with ordinary eyeglasses or contact lenses”.(ADP, 2008)

In the United States, low vision is defined as visual acuity worse than 6/12 but better than 6/60 in the better seeing eye (Maberley et al. 2005, Congdon et al. 2004, Tielsch et al. 1990). This is referred to as the North American definition.

In the United Kingdom low vision or partial sight is defined as (Dickinson 1998),

- visual acuity of 3/60 to 6/60 with full visual fields.
- visual acuity of <6/24 with moderate field constriction.
- visual acuity of >6/18 with gross field defects.

Blindness in the UK is defined as visual acuity of 6/120 or worse with intact visual fields or 6/60 or worse with markedly restricted fields (Dickinson 1998).

Leat and Bullimore (Leat et al. 1999) recommended defining low vision as visual acuity worse than 6/12. Moreover, they suggested that a visual acuity <6/7.5 should be classified as a visual impairment and that a person with any visual impairment who also experiences a disability should be classified as having low vision. Most people begin to experience disability when vision drops to less than 6/12. With visual acuity worse than 6/12 a person will not be able to easily perform a number of daily living tasks and reading will start to be affected. Some studies have used <6/12 as the lower (better) end of their visual limit (Tielsch et al. 1990, Gilbert & Ellwein 2008, Lamoreux et al. 2008)

1.1.2 Prevalence of low vision and blindness

According to the World Health Organization (WHO)(Resnikoff et al. 2004), there are more than 161 million people with visual impairment in the world: 37 million are blind and 124 million have low vision. This estimation was done by dividing the world into six different regions, see Table 1:1. As shown from this WHO estimation (Resnikoff et al. 2004), there are 15.53 million people with visual impairment in the Americas: 2.41 million are blind and 13.11 million have low vision.

Table 1:1 Number of people with visual impairment and blindness estimated globally by WHO (Resnikoff et al. 2004).

Region	Africa	Americas	East Mediterranean	Europe	South-east Asia	West Pacific
Blind people (millions)	6.78	2.41	4.02	2.73	11.58	9.31
Low vision people (millions)	19.99	13.11	12.44	12.78	33.49	32.48
Total visual impairment (millions)	26.77	15.53	16.46	15.52	45.08	41.79

Maberley et al. (Maberley et al. 2005) estimated the prevalence of low vision and blindness in Canada from three ophthalmology clinics in the city of Prince George in British Columbia based on the WHO and the North American definitions. They estimated the total prevalence of visual impairment for the Canadian population as 0.394%, 0.038% being blind and 0.356% having low vision. According to the North American definition, Maberley et al estimated a prevalence of 0.948% with visual impairment: 0.236% being blind and 0.712% having low vision. In Prince George city itself, the prevalence of low vision in adults between 65-74 years was 0.524% based on the WHO definition and 2.358% according to the North American definition. Among children younger than 19 years the prevalence was much lower. There were 0.04% children who had low vision based on the WHO definition and 0.12% according to the North American definition. The 2006 Participation and Activity Limitation Survey (PALS) by Statistics Canada (PALS 2006) examined self-reported disability in vision which was defined as "difficulty seeing ordinary newsprint or clearly seeing the face of someone from 4 meters (12 feet)". The results of the study showed that the total number of Canadians having difficulty in vision was 835,960. The number was 19,710 among children younger than 15 years. The percent prevalence in children is lower compared to adults, but it must be remembered that it is lifetime impairment.

In a study of self-reported visual disability in adults older than 65 years in Canada, Jin et al. (Jin & Wong 2008) asked the following question to determine visual disability "How is your eyesight (with glasses or contacts if you wear them)?" Participants had to choose one of the following responses; excellent, good, fair, poor or unable to see. If a "poor" response was given the person was classified as having poor vision. An "unable to see" response was considered as the person as being blind. The results of their study showed a prevalence of 6.8% with visual

impairment: 6.2% having low vision and 0.7% being blind. The results are high compared to the Maberley study and this may be due to the use of a question (i.e. self reported disability) and the way that visual impairment was defined. Also, participants in this study only included older adults which would explain the higher prevalence, although even when compared with the same age group in Prince George, the percentages are higher.

As shown by the Canadian statistics above (Maberley et al. 2005), the prevalence is lower in children than in adults. In the United States, Boyle et al. (Boyle et al. 1996) studied visual impairment in children and showed that 0.08% had visual impairment. They defined visual impairment as acuity of 6/20 to 6/150. In the UK, a study by Rogers (Rogers 1996) on the prevalence of visual impairment in children younger than 16 years showed a total prevalence of 0.18%, based on the WHO definition. Among those without additional disabilities, the figure was lower, 0.06%. In a more recent study in the UK, on children younger than 16 years, Rahi et al. (Rahi & Cable 2003) estimated that 0.06% had severe visual impairment or blindness which was interpreted as <6/60 or equivalent.

The prevalence of blindness and low vision varies enormously between countries. For example, a study on the prevalence and causes of blindness and low vision in adults in Beijing (Xu et al. 2006) using the North American definition showed higher figures; 2.2% of adults had visual impairment and 0.3% were blind. In Southern Sudan (Ngondi et al. 2006) across the whole population the prevalence was estimated to be 4.1% for blindness and 7.7% for low vision. The prevalence of both blindness and low vision increased with age. Among people between 5-29 years there was a prevalence of 0.5% for blindness and 1.8% for low vision. For 30-39 year olds it was 5.7% for blindness and 9.9% for low vision and among those over 50 years it was 22.9% for blindness and 39.9% for low vision.

A study was undertaken in children between 5 to 15 years by Gilbert (Gilbert & Ellwein 2008) in six different countries. The countries were India, China, South Africa, Nepal, Chile and Malaysia. Based on the WHO definition the overall prevalence of low vision was 0.033% which is quite close to Maberley's (Maberley et al. 2005) figure of 0.04% in children younger than 19 years.

Although the prevalence of low vision in children is always lower than in adults, it is life time impairment. If we think of it as impairment per year, it is a more serious issue than would appear from the prevalence numbers. A summary of the prevalence of low vision and blindness is shown in Table 1:2.

Table 1:2 Summary of the prevalence of visual impairment.

Country	Study	Adults/children	Definition used	Low vision	Blindness
Canada	Maberley et al. (Maberley et al. 2005)	Whole population	North American	0.712%	0.236%
	PALS(PALS 2006)	Whole population	Self report	Total = 835,960	Not reported
	Jin et al.(Jin & Wong 2008)	Adults >65 years	Self report	6.2%	0.7%
United States	Boyle et al.(Boyle et al. 1996)	Children	6/20 to 6/150	0.08%	Not reported
UK	Rogers (Rogers 1996)	Children including those with multiple impairments	WHO	0.18%	Not reported
	Rahi et al (Rahi & Cable 2003)	Children	UK (incidence of severe impairment)	0.06%	Not reported
Beijing	Xu (Xu et al. 2006)	Adults ≥40 years	North American	2.2%	0.3%
Southern Sudan	Ngondi, J et al. (Ngondi et al. 2006),	Whole population	WHO	7.7%	4.1%
Asia, Africa, and Latin America	Gilbert (Gilbert & Ellwein 2008)	Children	WHO	0.033%	Not reported

1.1.3 Causes of low vision

The main causes of blindness and low vision globally as reported by WHO (Resnikoff et al. 2004) are cataract (47.8%), glaucoma (12.3%) and age-related macular degeneration (AMD) (8.7%). These diseases affect millions of people globally. Cataract affects 18 million people in the world followed by glaucoma which affects 4.5 million people.

As reported by Maberley et al. (Maberley et al. 2005) the main causes of blindness and low vision in Canada are cataract (29.9%), AMD (13%) followed by visual pathway disorders (12%) and other retinal diseases (12%). According to the CNIB (Buhrmann 2007), the most common cause of low vision is age-related macular degeneration (AMD), followed by glaucoma and cataract.

Rahi et al. estimated the causes of blindness and low vision in children in the UK (Rahi & Cable 2003). The leading cause of blindness and low vision was retinal disorders (60.8%) particularly retinal dystrophies and albinism followed by disorders of the optic nerve (16.7%) particularly optic atrophy. Glaucoma accounted for 9.6% of the causes of blindness and low vision in the UK children. In another study on the causes of visual impairment in children in the UK, Rogers (Rogers 1996) reported that the major cause of visual impairment was albinism (22%), followed by hereditary retinopathy (19%) and congenital idiopathic nystagmus (16%). Cataract (13.8%), optic atrophy (13%), albinism (13%), congenital malformations (12.2%), glaucoma and retinitis pigmentosa (8.1%) were the major causes of visual impairment at a school for the blind in the United States (DeCarlo & Nowakowski 1999). Overall, in the UK and US, the most common causes of visual impairment in children are cataract, albinism, optic atrophy and glaucoma (DeCarlo & Nowakowski 1999, Rogers 1996, Rahi & Cable 2003).

1.2 Reading and magnification in young adults with low vision

Reading is a very important task in almost everyone's life. According to Elliot (Elliott et al. 1997), reading was the goal reported most frequently by adults during low vision rehabilitation. Without magnification, visual impairment may affect the person's ability to read. Children need to read during their education (Stelmack et al. 2008) and access to printed information is important for good academic success, although alternative methods can be employed for accessing printed information, e.g., voice output on a computer or Braille. Eye care specialists, teachers and parents should collaborate to help children and young adults with low vision successfully choose their optimum learning medium. The choice between Braille, large print or print with magnification should be considered in view of the person's reading skills, reading rate and accuracy, visual fatigue and working distance required (Wilkinson 1992). Generally it is preferable if a child can be enabled to read print with reasonable fluency so he or she can then learn in a fashion that is similar to their peers and potentially have access to a greater range of information. Visual reading is also preferable so children and young adults with low vision can use their visual experience to gain "incidental learning". Incidental learning is learning that happens outside a classroom or an instructional context (Bosman et al. 2006). Like children with normal vision, if children with low vision can access all written materials they would learn incidentally from i.e. road signs, package labels. Thus, they would attain a more natural visual experience. Children need to learn to gain education and the learning process requires good reading performance. According to Douglas et al. (Douglas et al. 2004), children with low vision lag in their reading (accuracy, comprehension and speed) compared to the norms of their age. Douglas also reported that the errors that children with low vision make are substitutions errors while normally sighted readers make mispronunciation errors. Gompel et al. (Gompel et al.

2004) showed that, like normally sighted children, children with low vision have no problem in comprehending text. However, they do take longer. Children with low vision need about 1 to 1 ½ more time to read a text than normally sighted children. Other studies have also shown that children with low vision read significantly slower than normally sighted children (Douglas et al. 2004, Gompel et al. 2004, Kartha 2010, Lovie-Kitchin et al. 2001). Gompel et al. suggested that teachers should give children with low vision more time to study and also extra time to complete exams. These reading difficulties that a child with low vision faces may affect the natural learning process and educational achievements.

The first impediment of reading for a person with reduced visual acuity is the print size. Young adults with low vision need some form of magnification to resolve print sizes that are below their visual acuity threshold (Wolffsohn & Eperjesi 2004). Fluent near-normal reading can be achieved with sufficient magnification in the majority of people with low vision (Lovie-Kitchin & Whittaker 2000).

1.3 Reading performance in low vision

The obvious way to help patients with reduced visual acuity who have reading difficulty is to magnify the text. Reading glasses/magnifiers are used to magnify text for patients with low vision. In 1956, Kestenbaum and Sturman (Kestenbaum & Sturman 1956) suggested a clinical rule to calculate a reading addition. Kestenbaum's rule is that the dioptric power of the reading addition equals the reciprocal of the distance visual acuity. Raasch (Raasch & Rubin 1993) reported that Kestenbaum's rule results in the person reading close to his/her acuity level. It tends to underestimate the required reading addition. Most derivations of Kestenbaum's rule

suggested multiplying this magnification by a factor of 1.5x to 2x (Raasch & Rubin 1993). This method does not consider the other factors that affect the reading performance as it deals with the print size only. In the early days of low vision rehabilitation, reading performance was evaluated by near acuity threshold only.

Legge (Legge et al. 1985a, Legge et al. 1985b) was the first researcher who systematically investigated reading performance for different text parameters and derived plots of reading speed as a function of print size for people with normal and low vision. He described how reading speed reaches a maximum or plateau across large print sizes and shows a cut off when print size is close to the reading threshold. He also defined what he called a critical print size which is the smallest print size, within the reading speed plateau, that allows the reader to read with maximum reading speed. Legge also suggested a method to calculate reading acuity more accurately. Reading performance in people with low vision is now often assessed by four functional measurements: reading speed, reading accuracy, critical print size and reading acuity.

1.3.1 Reading speed

To be able to read fast is a reasonable goal for all people with low vision. Slow reading rates may affect the person's understanding of the reading material and can be extremely frustrating (Dickinson 1998). Reading speed, also known as reading rate, is a measurement of the number of correct words read in a minute. Reading rate has now become a commonly used measure in the low vision literature to evaluate reading performance and is also considered by clinicians while prescribing magnification (Lovie-Kitchin et al. 2001, Whittaker & Lovie-Kitchin 1993, Ahn et al. 1995).

Reading speed can be affected by the level of difficulty of the reading material (Carver 1990) and the reading task (e.g. book or price tag). To compensate for the level of difficulty of reading materials, Carver (Carver 1990) suggested measuring reading rates in "standard word-lengths". A standard word is defined as having six characters.

The Minnesota Low-Vision Reading Test (MNREAD charts) was developed by Legge (Legge 2007) to measure reading performance as a function of print size. The charts consist of sentences in sequentially decreasing print size. The MNREAD sentences consist of 60 characters (ten words) of standard word length (six characters). The print sizes range from -0.5 logMAR to 1.3 logMAR. LogMAR is the logarithm of the minimum angle of resolution.

1.3.2 Critical print size (CPS)

Critical print size is defined as the smallest print size that allows the person to read with his/her maximum reading speed (Legge 2007). Critical print size is the smallest print size that is included in the reading speed plateau. It can be determined from the maximum reading speed plateau as determined by eye from the reading speed vs print size curve (Legge 2007). One method used to calculate the plateau is as follows: The average and the standard deviation for highest reading speed point and two adjacent points are calculated. The lower 95% range is given as the average - 1.96 x SD (Legge 2007) and this is used to check which other reading speed points fall within this range, which are then added into the calculation of mean and SD. This calculation is repeated until no other reading speed points fall within this 95% range. The CPS is the smallest print that is included in the 95% range. Some researchers have estimated the critical print size from curve-fitting procedures (Chung et al. 1998). Critical print size can be used to

help eye-care professionals in prescribing the optimal magnification for people with low vision (Mansfield et al. 1996). By knowing the smallest print size that allows the patient to read with maximum reading speed (CPS), the eye care professional can calculate the optimum magnification for that particular patient to read with maximum reading speed (Legge 2007).

1.3.3 Reading acuity

Near visual acuity can be measured clinically with near acuity charts which use isolated letters or unrelated words or sentences/paragraphs. Word reading acuity (reading text/sentences) is a different measure than the near letter acuity (reduced Snellen chart) but is highly correlated (Mansfield et al. 1996, Mansfield et al. 1993). Word reading acuity is usually worse than reduced Snellen acuity (Cacho et al. 2010, Lovie-Kitchin & Brown 2000). The difference between word reading acuity and reduced Snellen acuity is accounted for by the effects of greater degrees of crowding which makes reading words relatively harder (Legge 2007), although the context of the words would make reading sentences easier. The effect of crowding of nearby letters and words in word reading acuity (sentences/paragraphs) makes word reading more related to everyday reading tasks than letter acuity (Legge 2007). The word reading charts (e.g MNREAD charts) are designed to be used in low vision rehabilitation as it is a task that is more related to real world everyday reading tasks than letter acuity (Legge 2007).

Clinically, near visual acuity is recorded as the working distance used and the smallest print size seen (Elliott 2003). In 1967, Bailey and Lovie designed a distance acuity chart that uses a logMAR scale (Bailey & Lovie 1976). The logMAR chart has some great advantages over a traditional Snellen chart. A logMAR chart has the same number of letters on each line and the

same proportional space between letters and between lines (rows). The step size between lines is 0.1 logMAR. This makes the logMAR a great tool in measuring visual acuity in research. They also developed a near visual acuity chart which was based on similar principles (Bailey & Lovie 1980) and the MNREAD charts developed by Legge are also logMAR. The calculation of reading acuity or threshold suggested by Legge for the MNREAD charts (Legge 2007) has the advantage of taking into account the number of errors the reader makes while s/he is reading. Reading acuity using MNREAD charts is calculated in a similar way to the "letter-by-letter" method that is used for scoring distance visual acuity (Bailey et al. 1991). Each sentence is weighted as 0.1 logMAR and the total number of words that read incorrectly in each sentence is recorded. Reading acuity is given as a proportion of errors that the person made in each sentence multiplied by 0.1 and this is added to the smallest print size that the person attempted to read.

1.4 Devices for children with low vision

Low vision devices are prescribed to improve the child's visual abilities at near, intermediate and distance. Studies have shown that children may benefit from the use of a low vision device (Lee & Cho 2007, Leat & Karadsheh 1991). The type of the low vision devices prescribed depends on the child's needs with his/her parents' and teachers' involvement.

1.4.1 Relative distance magnification and near low vision devices in children with low vision

Relative distance magnification is defined as reducing the viewing distance to increase the retinal image size and thus gain magnification (Dickinson 1998). It is often the best way for

children and young adults with active accommodation to gain magnification. Children with low vision naturally hold the reading material at close distances as, unlike adults, they have active accommodation. They can exert some accommodation on close objects to obtain this relative distance magnification (Leat et al. 1999, Leat 2003, Silver et al. 1995). For aphakic or pseudophakic children or presbyopic adults, plus lenses must be used to compensate for the lack of accommodation.

However, studies have shown that many children with low vision have reduced accommodation (Leat & Mohr 2007) compared to controls of the same age. This is thought to be due to their poor visual acuity and possible decreased contrast sensitivity that are insufficient to stimulate an accurate accommodative response (Leat et al. 1999). Thus, some authors suggest that a near reading addition should be considered for these children (Leat et al. 1999). Also, as children get older, the amplitude of accommodation decreases, the print size in school materials decreases (Leat & Karadsheh 1991, Lovie-Kitchin & Bevan 1982, Leat et al. 1999) and the expected reading rate and amount of reading increases (Lovie-Kitchin & Bevan 1982). These factors also mean that a reading addition may be beneficial as the child ages.

The near low vision devices that have been prescribed for children vary between studies (Silver et al. 1995, McCurry et al. 2005, Lee & Cho 2007, Leat 2003, Ager 1998). Lee (Lee & Cho 2007) reviewed low vision devices for children with low vision but did not state what were the most common types of devices prescribed/used. Leat and Karadsheh (Leat & Karadsheh 1991), McCurry et al. (McCurry et al. 2005) and Silver et al. (Silver et al. 1995) reported that stand magnifiers were the most prescribed or used near low vision device. This might be because a stand magnifier is meant to stand on the reading material. Thus, it offers a more stable image

compared to hand-held magnifiers. Stand magnifiers also do not require any distance adjustments between the reading material and the magnifier (Lee & Cho 2007).

Nowadays, computers are widely used to magnify electronic text for reading and as a writing aid, even by children in the early grades. Children use computers for general education purposes (writing, reading and internet access etc). Adapted computers (computers with special software and/or larger screens) can make these functions possible for children with low vision. Electronic text can be magnified easily with a variety of magnifying programs, by changing the font size or zooming with the general computer facilities. For non-electronic text, scanners and digital cameras help to transfer any reading material to the computer which can be later magnified and adapted for the child's needs. Closed-circuit television (CCTVs) are made available for many children. A CCTV comprises a video camera which captures the image of the page which is then magnified onto the monitor screen (Dickinson 1998). The advantages of the CCTV compared to an optical aid are the high contrast of the image, wide field of view and range of higher levels of magnification (Dickinson 1998). They are, however, expensive and less portable than optical near visual aids.

Leat and Karadsheh (Leat & Karadsheh 1991) suggested regular low vision reassessments for children and whenever there is a change in school requirements and/or other activities. Despite children's changing needs, many children had not been assessed for low vision devices within one year (Leat & Karadsheh 1991). A study by Kelly (Kelly 2009) including children aged 6-12 years with visual impairment showed that between 59% and 71% of children who could benefit from an assistive device (enlarging software or text-to speech device) did not have the chance to use any high-tech (assistive technology) devices. A study in Canada of older adults (Mwilambwe et al. 2009) reported that 71% of people with visual impairment were aware

of the availability of low vision rehabilitation services. However, eighty one percent of the 71% who were aware of these services had benefited from them. This means that only 57.5% of the low vision populations are getting the services that they potentially need. Laitinen et al. (Laitinen et al. 2008), in a study of adults of 30 years and older with visual impairment, reported that only 31% of their sample received formal low vision rehabilitation services. Children might have difficulties in explaining their need for help or might not be aware of the availability of help, so it might be the case that children are getting even less access to services than adults.

The factors that determine reading performance in adults and children with low vision are discussed in Chapter 2.

1.4.2 Distance low vision devices

For distance tasks, the most practical low vision aid is a distance telescope (Dickinson 1998). They come in a variety of types and magnifications. They can be used to watch a soccer game or street signs and might be the best choice for outdoor activities. The largest disadvantage of using a distance telescope is its decreased field of view and the fact that it requires training for target searching techniques and good eye-hand coordination (Lee & Cho 2007). For distance tasks like watching television or reading the blackboard at school, the child can move closer to the object of regard (Dickinson 1998).

Electronic devices for distance viewing are also available. One device, the Jordy, consists of a head-mounted video camera that captures images which are displayed on two small LCD screens in a head-mounted device. The images can then be enlarged to a wide range of magnifications or can be connected to a TV or DVD. As with table mounted CCTVs, images can

be presented in colour, black and white or reverse contrast. Some types of these electronic devices have an auto-focusing option which make them easier to use for a variety of tasks at different working distances.

1.5 Accommodation

1.5.1 Definition

Ocular accommodation is defined as the ability of the eye's crystalline lens to change its optical power to maintain an in-focus image across a wide range of viewing distances. Ocular accommodation is an important function to achieve an in-focus retinal image. When the eye accommodates for a near target, the ciliary muscle contracts, causing the zonules to relax. The crystalline lens contracts and changes its shape to become more convex. The crystalline lens thus increases its dioptric power for near work (Helmholtz theory or classical theory, see Garner. 1983 (Garner 1983).

1.5.2 Methods of assessing accommodation

1.5.2.1 Amplitude of accommodation

The dioptric value of the far point (point that is conjugate with the retina when accommodation is fully relaxed) minus the dioptric value of the near point of accommodation (point that is conjugate with the retina when accommodation is fully exerted) is the calculated amplitude of accommodation (Rosenfield & Logan 2009). The most common clinical method used to measure the amplitude of accommodation is the push-up technique. The goal of this

method is to locate the near point of accommodation when the patient is fully corrected with his/her distance refraction, i.e, to locate the far point at infinity. In this technique, the observer looks at a detailed near target and is asked to keep it as clear as possible. The examiner moves the target towards the person's eyes and asks him/her to report the first sustained blur of the target. The reciprocal of the distance (in meters) between the target at the position of the first reported sustained blur to the observer's spectacle plane is the near point of accommodation (in dioptres). This method is a subjective method. It depends on the observer's response and it is ineffective for people with cognitive challenges, young children or people with low vision who cannot clearly resolve the target.

1.5.2.2 Autorefractors

Many commercial infrared autorefractors (i.e. WAM5500 from Grand Seiko) can be used to measure the accommodative response. These instruments measure the accommodation response objectively and rapidly. They are also easy to use.

Dynamic retinoscopy is an objective method to assess the accommodative response. Hence, it is a good method to use with young children and other patients who cannot respond accurately for the subjective push-up method. Dynamic retinoscopy was described by Cross (Cross 1911) and refined by Nott (Nott 1925). In the Nott technique (Nott 1925), the patient is asked to look at a near point target (with enough detail to stimulate accommodation) with his/her full distance refractive correction in place. The examiner shines the retinoscopy light through a hole in the near point card. The examiner moves until a neutral reflex is observed. The lag of accommodation is the difference between the reciprocal of the distance (in meters) from the

retinoscopy peephole to the participant's eye minus the dioptric distance between the participant's eye and the target (when the neutral reflex is observed behind the target).

Woodhouse et al. (Woodhouse et al. 1993) developed a modified Nott retinoscopy technique. A modification was made to the stimulus - they used an illuminated cube fixed on an amplitude rule marked in centimeters. The cube has black-on-white pictures, letters and numbers on each side that would be resolvable by people with a range of visual acuities and also that would be interesting for young children. The ruler has a chin rest and the cube could be moved for a range of accommodative demands. The patient views the target binocularly and is asked to try to keep it as clear as possible. To keep the patient's interest, the examiner asks the patient to read/describe the numbers/picture. A lag of accommodation is obtained when the neutral point is further away from the patient than the target and a lead of accommodation is when the neutral point is closer to the patient than the target. The dioptric difference of the distance of the retinoscopy sight-hole from the eye and the target from the eye when a neutral reflex is observed represents the lag of accommodation (Figure 1:1).

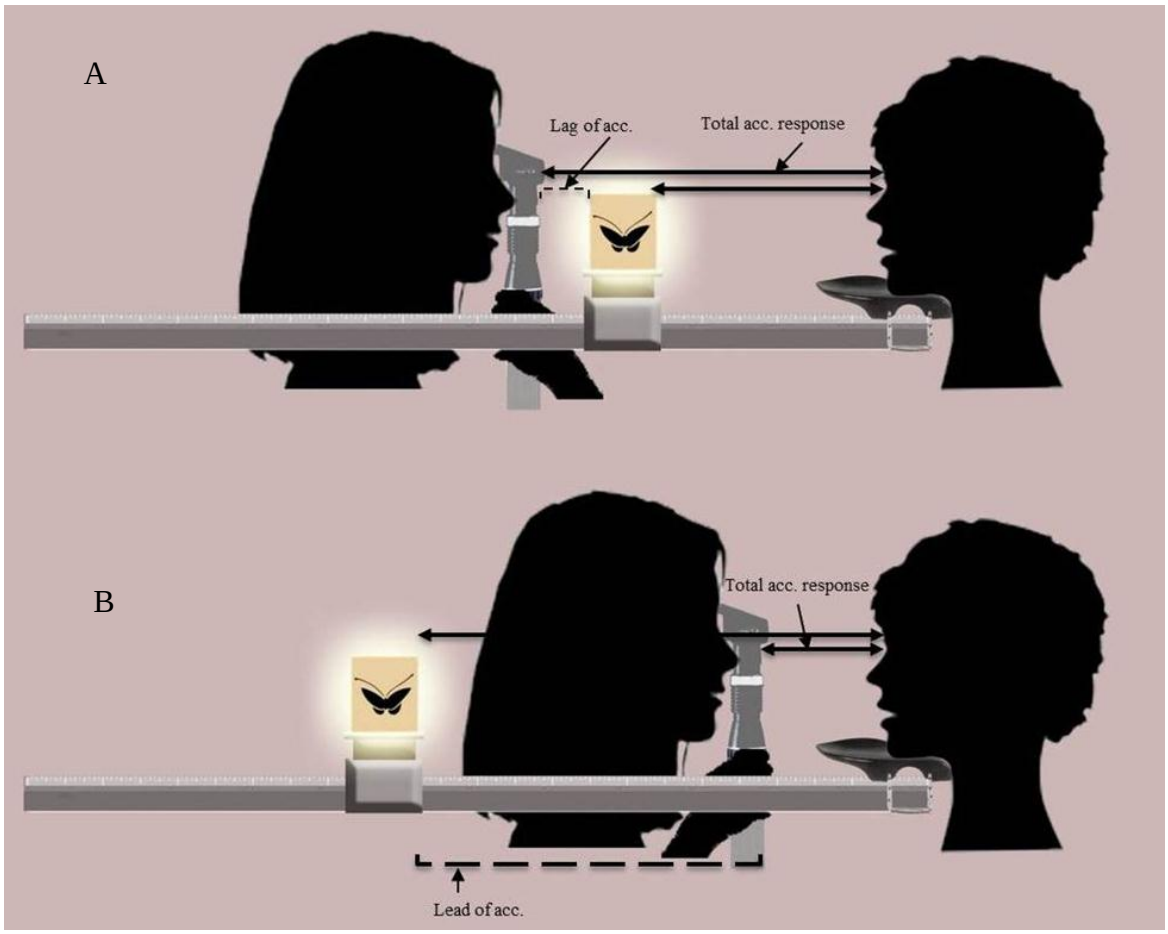

Figure 1:1 Demonstration of the determination of the lead and lag of accommodation. Solid lines show the total accommodative response and the accommodation demand. A. Lag of accommodation and B. Lead of accommodation.

McClelland and Saunders (McClelland & Saunders 2003) studied the repeatability and validity of the dynamic retinoscopy technique compared to the Shin-Nippon SRW-5000 Autorefractor at 4D, 6D and 10D demands. The results showed that the test and re-test results for dynamic retinoscopy were not significantly different from each other (paired t-test, $p > 0.1$). The coefficient of repeatability for the modified dynamic retinoscopy was ±0.56 D for the 4 D

demand, ±1.09 D for the 6 D demand and ±1.34 D for the 10 D demand. Importantly, the results also showed that there was no significant difference in the results obtained by dynamic retinoscopy and Shin-Nippon SRW-5000 Autorefractor (two tailed paired t-test, $p > 0.1$). The authors concluded that the dynamic retinoscopy technique is a repeatable and valid measure of the accommodative response.

In another study (Leat & Mohr 2007), the inter-observer repeatability of measuring the accommodative response with the dynamic retinoscopy technique was studied. The results showed that there was no significant difference between measurements that were obtained by two examiners ($p=0.89$). The coefficient of inter-observer repeatability was 0.372D, 0.667, 0.708 and 0.764 for stimulus demands of 4D, 6D, 8D and 10D respectively.

To conclude, the dynamic retinoscopy technique has been found to be rapid and reliable and has been used in many different studies (Leat & Gargon 1996, McClelland & Saunders 2003, Woodhouse et al. 1993, Leat & Mohr 2007).

1.5.3.2 Normal values of lag of accommodation

Normal accommodation response ranges have been measured (McClelland & Saunders 2003, Leat & Gargon 1996) using modified Nott dynamic retinoscopy for different age groups and different distances. These can be used to determine if a person's accommodation response falls within the normal ranges.

These studies have shown that the lag of accommodation increases with age and accommodative demand. Leat and Gargon (Leat & Gargon 1996) showed that the lag of

accommodation increased as the demand increased. The 6-10 age group showed an average lag of 0.3 D at 4 D demand, 0.5 D for 6 D demand and 1.12 at 10 D demand. For an older group, 11-26 years, the lag of accommodation was 0.59 D at 4 D demand which increased to 2.93 D at 10 D demand. Similarly, in study by McClelland and Saunders (McClelland & Saunders 2003), the mean lag of accommodation increased in 4 year old children from 0.30 D for 4 D demand to 2.46 D at 10 D demand.

1.5.4 Factors that affect accommodation

1.5.4.1 Age

As early as 1864 the decline in the amplitude of accommodation was documented by Donders (Donders 1864). As the person gets older, the eye gradually loses its ability to focus accurately on near targets. Without correction, reduced accommodation ability due to aging will affect the person's ability to perform near tasks including reading performance. This age-related drop in the amplitude of accommodation is called "presbyopia". Presbyopia is usually corrected by the use of plus lenses in adults (a near or reading addition).

1.5.4.2 The stimulus to accommodation

The basic stimulus to accommodation is defocus blur (Ciuffreda 1991a). There is a stimulus to accommodation when the target of interest becomes blurred i.e. the retinal defocus exceeds the depth of focus of the eye. The target used to stimulate accommodation should have particular characteristics. It should contain enough detail to stimulate accommodation. The size

of the target used should be an appropriate size for the patient's visual acuity. Also, it should be of high contrast if it is to be used with low vision patients. Ciuffreda (Ciuffreda 1991b) showed that the accuracy of the accommodative response can be affected by the spatial frequency and the contrast of the target. In observers with normal vision, he showed that when the contrast of the target is reduced beyond a certain level (-10dB), the accommodative response decreases and returns to its tonic level. Ciuffreda (Ciuffreda 1991a) also showed that retinal image eccentricity and motion decreases the accommodative response. As the retinal image eccentricity and motion increases, accommodation decreases and shifts to its tonic level.

For low vision patients with poor visual acuity presumably it will be more difficult for them to detect blur to stimulate an accurate accommodative response. Also they will be more affected by the low contrast sensitivity and the effect of low contrast in the object of interest. Moreover, low vision patients will have more difficulty picking up cues which control the direction of the accommodation response i.e. chromatic aberration, size and proximity. Many low vision patients have one or more of these anomalies that would affect the accuracy of their accommodative response and lead to a poor accommodative response compared to a person with normal vision.

1.5.5 Accommodation in children and young adults with low vision

People with low vision have reduced visual acuity and possibly also reduced contrast sensitivity. It has been suggested that an unclear retinal image in young adults with low vision is inadequate to drive the normal accommodative process and thus these patients have reduced accommodation (Jackson & Saunders 1999). In other words, they are less able to use blur as a

cue to stimulate an accurate accommodative response. Leat suggested that young adults with low vision have reduced accommodation accuracy because of increased depth of focus due to poor visual acuity (Leat & Mohr 2007). Low vision patients often have difficulty detecting objects with low contrast. Reduced contrast sensitivity in people with low vision probably also decreases the accuracy of their accommodative response (Rubin & Legge 1989).

Indeed, reduced accommodation has been documented in various populations who also tend to have reduced acuity (McClelland et al. 2006, Leat 1996, Leat & Gargon 1996, Woodhouse et al. 1993, Leat et al. 1999). Woodhouse et al. (Woodhouse et al. 1993) reported that 80% of children between 6 to 11 years with Down syndrome have reduced amplitude of accommodation compared to normal children. Another study by Leat (Leat 1996) showed that 46% of children and young adults with cerebral palsy have reduced accommodation accuracy.

Ong et al. (Ong et al. 1993) documented reduced accommodation in people with congenital nystagmus. White and Wick (White & Wick 1995) showed that people with juvenile macular degeneration, who have central retinal abnormalities and reduced visual acuity, have reduced accommodative response compared to people with normal vision. Hokoda and Ciuffreda (Hokoda & Ciuffreda 1982) found reduced accommodative response in individuals with amblyopia. Reduced accommodation was also reported in people with achromatopsia (Heath 1956). Leat and Mohr (Leat & Mohr 2007) showed that 86% of children and young adults with low vision due to a variety of disorders had reduced accommodation compared to controls of the same age group. Children and young adults with low vision have reduced visual acuity and reduced contrast sensitivity, eccentric fixation and abnormal eye movements that may all affect their ability to achieve an accurate accommodation response.

People with low vision often have difficulties with near work tasks. They tend to use closer than average reading distances (Leat & Mohr 2007) to obtain relative distance magnification. Some authors e.g. Nowakowski (Nowakowski 1994), have suggested that children with low vision have active accommodation and can focus for these close working distances. Faye (Faye 1984) suggested that children with low vision have plenty of accommodation. In fact, she suggested that they have more than would be predicted for their age and that they can sustain prolonged accommodative effort. She suggested that usually children with low vision do not need any low vision aids for near work and that reading glasses should be only considered when a child has a "history of blurring after prolonged reading or inability to read a particular part of the assignment". Other authors have suggested that the prescription of a reading addition should be considered for children and young adults with low vision (Leat & Mohr 2007, Leat 2003, Leat et al. 1999, Dickinson 1998). Leat (Leat et al. 1999, Leat 2003) suggested a way to prescribe a reading addition for low vision patients based on their age and amplitude of accommodation.

1.6 Work to date

In a previous study in our laboratory (Leat et al. 2010), reading performance was evaluated in pre-presbyopes by the measures of maximum reading speed, critical print size, reading acuity and area under the reading speed curve with a reading addition determined by a dynamic retinoscopy technique. The results showed that reading acuity and the area under the reading speed curve improved with the dynamic retinoscopy addition. There was no improvement in the maximum reading speed or the critical print size. It was suggested that

reading additions might be beneficial to improve reading performance in young people with low vision and should be considered in the routine low vision assessment of such patients.

Maximum reading speed and the critical print size did not show any significant improvement and this might be because of the method that was used to determine the reading addition. In the present study, three methods to determine a reading addition are investigated. Reading performance is evaluated by a measure of maximum reading speed, critical print size, reading acuity and area under the reading speed curve.

Chapter 2: Reading in children with low vision

2.1 Factors that determine reading performance in adults and children with low vision

This section is published as follows

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This article was written by Balsam Alabdulkader. Guidance, editing and suggestions were given by Susan Leat.

2.1.1 Overview

There have been numerous and extensive studies into the visual requirements for reading in adults with low vision. There are far fewer studies involving children with low vision. This article compares the studies on children which do exist with the findings in adults. Acuity reserve (magnification), contrast reserve and visual field requirements are considered. We also review the literature which compares the efficacy of large print with optical magnification for children. From the few studies that exist, there are indications that the requirements for children are not the same as for adults. Therefore, we suggest that one cannot directly apply the results from adults to children and that there is a gap in the literature (and therefore our understanding) of the visual requirements for reading in children.

2.1.2 Introduction

Visual impairment is a globally prevalent issue in both adults and young populations. According to World Health Organization (WHO), (World Health Organization 2009) in 2002 there were more than 161 million visually impaired people. Thirty-seven million people were blind and one-hundred twenty four million people had low vision. Low vision interferes with many daily activities. It affects a person's academic and economic life and even his/her social life. Patients with low vision have many different goals for their low vision rehabilitation. Reading is one of the most common goals reported by adults with low vision (Elliott et al. 1997). Unlike adults with low vision, low vision may cause a lifelong reduction in a child's visual performance (Bevan et al. 2000). Reading is one of the main avenues for education and educational achievement. If visual impairment affects the child's ability to read, it could be a great impediment of his/her educational success (Lovie-Kitchin et al. 2001). Reading is a first step in education and is a predictor of good academic success (Stelmack et al. 2008). The first barrier to reading for most children with low vision is the print size. Children with low vision usually need some form of magnification to resolve letters that are lower than their threshold (Wolffsohn & Eperjesi 2004). During a low vision assessment, reading performance is not assessed expect for a brief assessment of thresholds and fluency (Kalloniatis & Johnston 1990). With a detailed low vision examination and an accurate visual correction, children might achieve a better reading performance. There are other examinations than visual acuity that should be included in the low vision examination. Acuity reserve and contrast reserve are good predictors of reading performance in adults and are likely to be important in children. The optimum magnification, acuity reserve and contrast reserve tend to lead to the optimum possible reading fluency.

In this paper we review the literature that relates to visual reading in children with low vision with an emphasis on visual requirements in terms of acuity (or magnification), contrast and visual field.

2.1.3 Relationship to Visual Acuity

A typical low vision examination always includes a visual acuity test. Visual acuity on its own used to be considered as the only predictor of reading ability (Whittaker & Lovie-Kitchin 1993). Recent studies have shown that this is not the whole story (Whittaker & Lovie-Kitchin 1993, Rubin & Legge 1989). Whittaker and Lovie-Kitchin (Whittaker & Lovie-Kitchin 1993) defined the Acuity Reserve as the ratio of the print size of the reading material to the subject's visual acuity threshold for a particular print being read. With a 1:1 acuity reserve i.e., or no acuity reserve, patients can still read, but very slowly. With the optimum acuity reserve patients can read more easily and have a higher reading rate. Whittaker and Lovie-Kitchin used published data from three previous studies (Legge et al. 1985a, Legge et al. 1985b, Lovie-Kitchin & Woo 1988) and re-plotted the results to show the effect of acuity reserve on reading speed. Also, they indicated that the majority of low vision professionals tend to work with patients who, at the time of assessment, had an acuity reserve of 3:1 or less. An acuity reserve of 18:1 was the maximum of the optimum acuity reserve range and with higher reserves than this, the reading rate drops. For most adults an acuity reserve between 6:1 and 18:1 is required to achieve maximum reading rate (Whittaker & Lovie-Kitchin 1993).

Kestenbaum and Sturman (Kestenbaum & Sturman 1956) suggested a rule to calculate the reading addition for a given visual acuity. Kestenbaum's rule is that the reading addition

equals the inverse of the visual acuity. It tends to underestimate the reading addition for a patient (Raasch & Rubin 1993) and results in the person reading close to the resolution limit. Kestenbaum's rule is mainly used as a starting point for the required reading addition. Most derivatives from Kestenbaum's rule reported an additional magnification factor to the original rule of 1.5 to 2.0x (Raasch & Rubin 1993). Clinically, professionals suggested more magnification or acuity reserve for better reading performance (Raasch & Rubin 1993). Raasch and Rubin, in a study of patients with age-related macular degeneration, argued that patients need 6x or maybe more than Kestenbaum's rule to achieve the maximum reading rate (Raasch & Rubin 1993).

In a study on sighted children by Lueck et al, (Lueck et al. 2000) a comparison was made of the required visual acuity reserve for reading text and unrelated words. The results indicated that four times acuity reserve is needed for sighted children to read text materials aloud. Less acuity reserve is required to read unrelated words.

A more recent study of Lueck et al. (Lueck et al. 2003) showed that children with low vision need at least three times the acuity reserve to read efficiently. This results in much larger print sizes being required for children with very low visual acuities in order for them to gain the optimum acuity reserve. Lueck et al. (Lueck et al. 2003) reviewed some ways that help children with low vision achieve the optimum acuity reserve. These include decreasing the reading distance, increasing the print size material or using a low vision aid.

Lovie-Kitchin et al. (Lovie-Kitchin et al. 1994) reported a study of adults and children with low vision that showed that the acuity reserve for children should be between 2.5:1 and 8:1 and between 2:1 and 8:1 for adults for maximum reading rates to be achieved. These results are

lower than Whittaker and Lovie-Kitchin (Whittaker & Lovie-Kitchin 1993) found for adults but there is some overlap.

In another study on children by Lovie-Kitchin et al, (Lovie-Kitchin et al. 2001) acuity reserve between 2.5:1 to 7:1 was necessary to achieve maximum reading rate. Patients with lower visual acuities tend to achieve maximum reading rate with less acuity reserve, which was an unexpected result in this particular study and in contrast to Lueck et al. above (Lueck et al. 2003). Interestingly they found that, unlike adults with low vision, age was a better predictor of reading rate than near visual acuity in children with low vision.

A variety of reading tests have been used for these studies. Some studies have used standardized tests of reading and some researchers have developed their own tests of reading based on similar principles. Figure 2:1 and 2:2 show examples of reading cards that have been used. Lueck et al. (Lueck et al. 2000, Lueck et al. 2003) used the Bailey-Lovie Word reading cards and sentences from the MNREAD test (Figure 2:2) while Lovie-Kitchin et al. (Lovie-Kitchin et al. 1994) used the Bailey-Lovie Word reading cards and charts created from standardised children's texts.

Thus, there are only three studies on how much acuity reserve is needed for children to achieve maximum reading rate. It ranged between 2.5:1 and 8:1. Further studies for children should be done to confirm these results. Table 2:1 summarizes the results of studies that measured acuity reserves in adults or children.

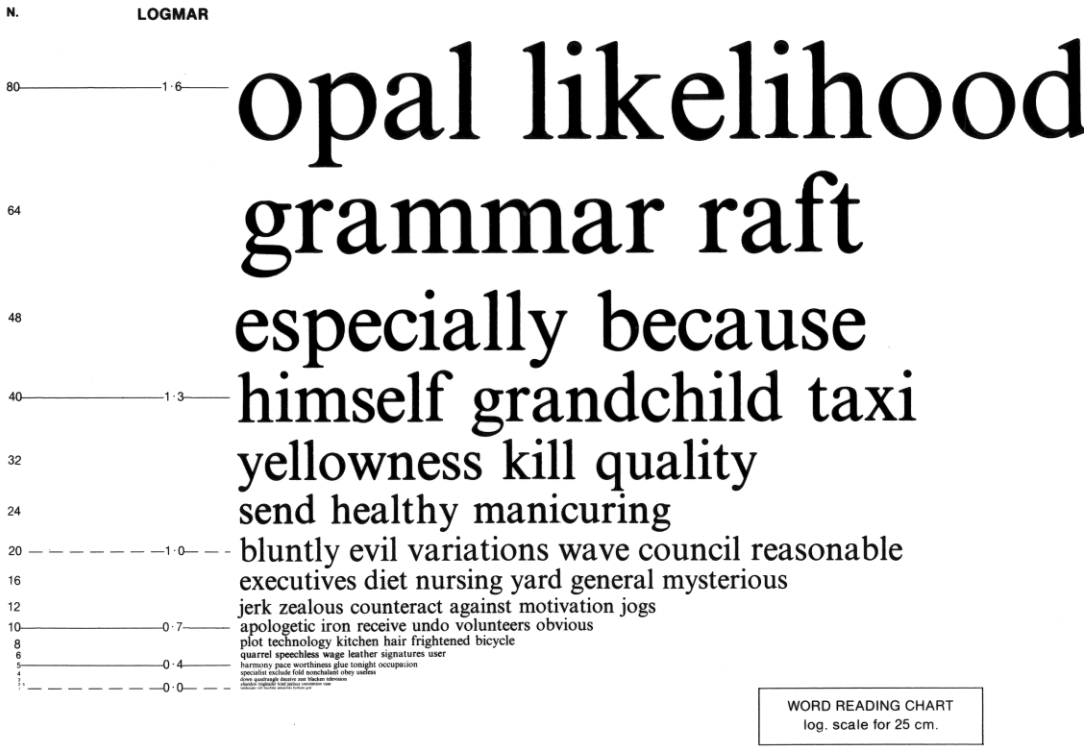

Figure 2:1 An example of the Bailey-Lovie Word reading card.

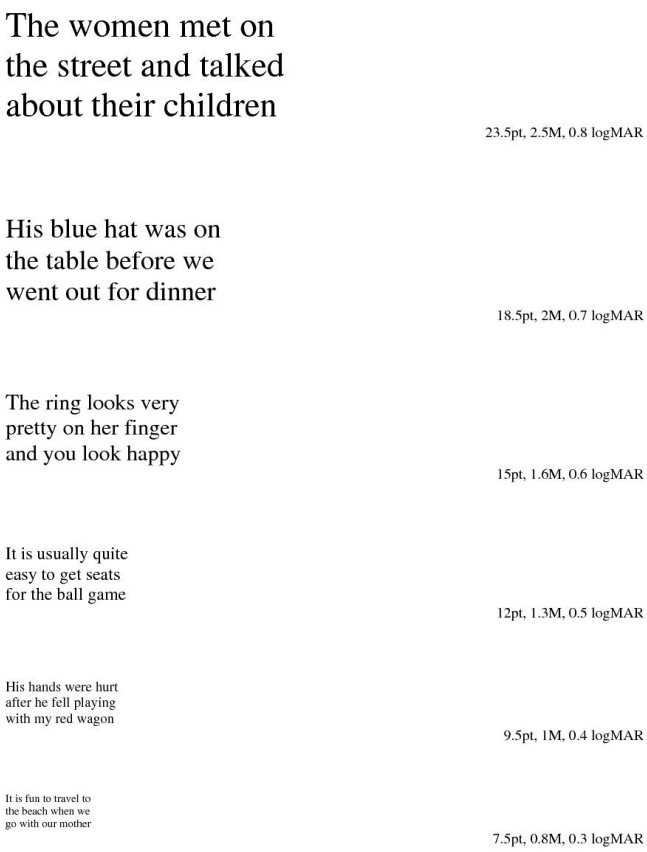

Figure 2:2 An example of MNREAD sentences and their format.

2.1.4 Relationship to type of magnification

The first common impediment of reading for low vision patients is the text print size. Different methods can be used to magnify text and give better reading performance. In the literature on this subject, eye care professionals and educators have debated whether it is more beneficial to use a magnifier or large print text to obtain magnification. According to McCurry et al, (McCurry et al. 2005) most children with low vision tend to benefit from using magnifiers to read standard print. In this study, all of the children underwent a regular low vision assessment of their visual performance. This included a reading performance evaluation using a magnifier. The study's aim was to determine the effectiveness of using magnifiers to read standard print size. The results showed that near vision performance was improved for 28% of the children with spectacles and/or magnifiers and that 54.3% of the children were enabled to read standard print size. Also, nearly half of the children showed improvement in their reading and/or writing skills with spectacles and/or magnifiers. In addition, the study reported that most magnifiers used were stand magnifiers. This study is in agreement with Leat and Karadsheh's (Leat & Karadsheh 1991) study, in which it was reported that stand magnifiers tend to be the first choice of near low vision aids by children.

Farmer and Morse's study (Farmer & Morse 2007) made a comparison between two groups of children. The first group of children used large-print text for reading while the second group used magnifiers. The results showed that the first group had an increase in reading speed rates but with no significant increase in reading comprehension skills. On the other hand, the second group of children showed an increase in their reading speed rates and a noticeable increase in their reading comprehension skills.

In a study by Kalloniatis and Johnston, (Kalloniatis & Johnston 1990) children's clinic files were reviewed to find relevant data. Then the children's reading performance was assessed in their regular classroom with the use of their low vision aids. In general, the children had a high rate of low vision aids usage. More specifically, it was also found that the children's vision could be improved by using simple low vision aids. The study concluded that the children preferred to move their reading material closer (use a close reading distance) than to use a low-powered near low vision aid.

In the study by Silver et al, (Silver et al. 1995) which included 230 children at a school for the blind, visual acuity was used to determine the need for magnification or glasses. The majority of these children (57%) were only taught Braille and treated as totally blind, although 79% of these children could benefit from near low vision devices or reading spectacles and be enabled to read normal print. This study raises the importance of magnification, and the effect on the children's academic life. This study also reported that stand magnifiers seem to be the easiest optical magnifiers for children to use.

Thus there is only one study that directly compares optical magnification with large print and this showed that using magnifiers was more effective compared to providing large print text. Many studies, however, have described the benefits of optical magnification (Silver et al. 1995, Farmer & Morse 2007, McCurry et al. 2005, Bevan et al. 2000) to help children with visual impairment to read. Using magnifiers does not limit the childrens' reading material to that which is enlarged only and allows children to access any written information in normal print size. Producing large print books is expensive. However, enlarging photocopying is more available nowadays and also changing the font size on a computer document is easy. Magnifiers are also the only option for children who require higher levels of magnification for whom providing large

print materials is impossible, although a combination of large print and optical magnification is also an option. Thus it seems that, for better education achievement, children with low vision should be assessed for magnifiers and be taught and trained how to use them effectively.

2.1.5 Relationship to Contrast Reserve

According to Whittaker and Lovie-Kitchin, (Whittaker & Lovie-Kitchin 1993) the ratio of the letter contrast to the subject's contrast threshold for a reading print is defined as the Contrast Reverse. Decreased print contrast and also decreased contrast sensitivity of the observer results in a reduction of the contrast reserve. In this study of adults with low vision, Whittaker and Lovie-Kitchin used published data from three different experiments (Rubin & Legge 1989, Legge GE 1987, Brown 1981). Results were re-plotted together and it was found that decreasing contrast reserve resulted in declined reading rate. People with normal sight also experience low reading rates if the contrast reserve is less than 20:1 (Whittaker & Lovie-Kitchin 1993). Whittaker and Lovie-Kitchin (Whittaker & Lovie-Kitchin 1993) suggested that the optimum contrast reserve for maximum reading rate is higher than 30:1 and for high fluent reading a reserve of 10:1 is required. Also, it was found that for 6 degree letters the majority of patients with low vision have a 0.10 or higher contrast threshold (Rubin & Legge 1989). Thus patients with low vision have reduced reading rate because, even with video magnifiers that give a contrast of almost 1 (100%) and plenty of magnification, their contrast reserve may be less than 10:1 (Whittaker & Lovie-Kitchin 1993).

In a study of young normally sighted adults, Mohammed and Dickinson, (Mohammed & Dickinson 2000) studied the effect of contrast reserve on reading performance. This was

evaluated by comparing different magnification powers with controlled field of view. It was found that providing the patient with higher magnification could not compensate for a low contrast reserve and thus lead to a more optimum reading rate. It was found that reading performance declined whatever the level of magnification if the contrast reserve was lower than 10.5:1, which is in agreement with the study by Whittaker and Lovie-Kitchin. (Whittaker & Lovie-Kitchin 1993)

According to Leat and Woodhouse, (Leat & Woodhouse 1993) contrast sensitivity was a predictor of reading speed. The study included 30 adult subjects. The authors concluded that contrast sensitivity at 0.5c/deg was correlated with reading performance and contrast sensitivity at high spatial frequencies was a poorer predictor of reading speed compared to contrast sensitivity at the lower spatial frequencies. The study suggested that contrast sensitivity should be included in a regular low vision assessment.

A recent study by Lovie-Kitchin et al, (Lovie-Kitchin et al. 2001) the only study of contrast sensitivity and reading in children, found quite different results than those reported in adults with low vision (Whittaker & Lovie-Kitchin 1993, Mohammed & Dickinson 2000, Leat & Woodhouse 1993). In this study, the contrast sensitivity for 71 students (aged 7-18 years) was measured at low to mid spatial frequencies. However, it must be noted that the children generally had relatively good contrast sensitivity. Only four children had contrast sensitivity less than 10. It was concluded that, unlike adults with low vision, contrast sensitivity was not a good predictor of reading rate in children with low vision and it would not be helpful to include a contrast sensitivity measurement routinely in a clinical low vision assessment for reading in this population. Table 2 summarizes the results of studies that measured contrast reserves in adults or children.

2.1.6 Relationship to Visual Field

In the study by Whittaker and Lovie-Kitchin, (Whittaker & Lovie-Kitchin 1993) the results of two studies (Legge et al. 1985, Lovie-Kitchin & Woo 1988) of adult subjects with normal and low vision were re-plotted. It was found that, for both normal and low vision subjects, reading rate increased as field of view increased. Subjects with low vision use low vision devices and usually need to move the reading material as close as possible to the eye (Whittaker & Lovie-Kitchin 1993). The authors suggested that the field of view restricted by simple low vision devices is not significant. It was also concluded that, if people with low vision are taught to manipulate the low vision device and place the text within the field of view of the device, a large field of view is not necessary for fast reading rate.

In a study by Legge et al, (Legge et al. 1992) 141 adults with low vision were included. The study's aim was to determine which clinical measurement was a good predictor of reading speed. Field of view was examined by Goldmann perimeter or tangent screen. If the subject had a scotoma that covered all or part of the central 5° of the visual field he/she was classified as having central loss. If not, he/she was classified as having central field intact. It was found that central visual field loss was associated with slow reading speed. It was, however, not a predictor of slow reading speed. On the other hand, it was found that the majority (74%) of slow readers had central loss.

According to Gompel et al, (Gompel et al. 2004) visual field defects do not affect children's reading speed and comprehension. This study compared two groups of children with low vision. The first group included children with low vision who had visual field restrictions and the second group were children with low vision and intact visual fields. Interestingly, no

differences in reading speed and reading-comprehension skills were found between these two groups of children with low vision. This is the only study on the effect of visual field constrictions on reading speed rate in children with low vision. More studies need to investigate the importance of field of view on reading speed in children with low vision.

4.1.7 Conclusion

Adults with low vision can read effectively when the main criteria for good reading are met. These include magnification, acuity reserve, contrast reserve and visual field. Little is known about the similar requirements for children. It does appear that acuity reserve should be at least 2.5:1 (Lovie-Kitchin et al. 1994, Lovie-Kitchin et al. 2001). This can be achieved by increasing the magnification which may possibly help to compensate for any low contrast reserve. There have been no studies that have investigated the minimum contrast reserve required for children with low vision to read easily, although one study showed that contrast sensitivity may be less of a limitation in young people than older adults. In adults, a contrast reserve of more than 10:1 (Whittaker & Lovie-Kitchin 1993, Mohammed & Dickinson 2000) is needed to achieve the optimum reading speed rate. Using electronic magnifiers or high contrast print could help to compensate for low contrast sensitivity for the children with low vision and good illumination may improve contrast sensitivity in some cases. Children with clear media and intact central visual field should be able to read reasonably well. Adequate magnification resulting in a good acuity reserve and contrast reserve would be expected to lead to better reading performance. Thus there are indications that children do not perform in exactly the same way as adults (Lovie-Kitchin et al. 2001) and the adult data may not be directly applicable to

children. Further studies for children should be done to further investigate the parameters that may affect childrens' reading performance so as to further our knowledge and improve the clinical assessment of reading and provision of reading aids in children.

Table 2:1 Studies of acuity reserve

Study	Type of study	Subjects	Results
Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001)	Reading performance and vision measures compared	Participants with low vision aged 7-18 years	Acuity reserve between 2.5:1 and 7:1 is required for children and teenagers
Whittaker and Lovie-Kitchin (Whittaker & Lovie-Kitchin 1993)	Collected data from three previous studies (Legge et al. 1985a, Legge et al. 1985b, Lovie-Kitchin & Woo 1988)	Adult with normal and low vision(Legge et al. 1985a, Legge et al. 1985b, Lovie-Kitchin & Woo 1988)	Acuity reserve between 6:1 and 18:1 is required for optimum reading
Lueck et al (Lueck et al. 2000)	Reading rates measured for print of different sizes and distances	11 4th graders with normal vision	Acuity reserve of $\geq$ 2.5 required.
Lueck et al. (Lueck et al. 2003)	Reported values from Lueck et al. (Lueck et al. 2000) Reading rates measured for different print sizes and distances	11 sighted 4th graders 6 children with low vision	Acuity reserve between 1.25x and 4x required. Acuity reserve of $\geq$ 3x required
Lovie-Kitchin et al. (Lovie-Kitchin et al. 1994)	Print sizes that give maximum reading rates for adults and children	Adults aged 20-73 years and children aged either 7 or 8 years with normal vision	Acuity reserve between 2:1 and 8:1 required for adults Acuity reserve 2.5:1 and 8:1 required for children

Table 2:2 Studies of contrast reserve

Study	Brief description	Subjects	Results
Whittaker and Lovie-Kitchin(Whittaker & Lovie-Kitchin 1993)	Collected data from three previous studies(Rubin & Legge 1989, Legge GE 1987, Brown 1981)	Adults with normal and low vision(Rubin & Legge 1989, Legge GE 1987, Brown 1981)	Contrast reserve of >30:1 required
Mohammed and Dickinson(Mohammed & Dickinson 2000)	Effect of low contrast reserve on reading performance with different magnifications	Young university students with stimulated low vision	Contrast reserve of >10.5:1 required

Chapter 3: Aims and hypotheses

3.1 Purpose of the study

In previous studies it was suggested that the degraded visual image in young adults with low vision is inadequate to drive the normal accommodative process and that this is the reason these patients have reduced accommodation (Jackson & Saunders 1999, Leat & Mohr 2007). One way of compensating for reduced accommodation in young adults with low vision is the prescription of a near addition. A few authors (Leat et al. 2010, Leat & Karadsheh 1991, Leat et al. 1999, Leat 2003, Lovie-Kitchin & Whittaker 1999) discussed the possibility that young adults with visual impairment may benefit from a reading addition. To the author's knowledge, there is only one previous study to determine whether young adults with low vision will benefit from a reading addition (Leat et al. 2010). Leat (Leat 2003) suggested a clinical method to estimate a reading addition for young adults with low vision based on the person's expected accommodation level for his/her age. However, there have been no studies to verify the best method to determine the reading addition to be prescribed in young adults with low vision. Given the potential importance of prescribing a reading addition for young adults with low vision and the likelihood that a reading addition might improve their reading performance, this study was designed with the following objectives:

1. To determine if three methods of determining a reading addition for young adults with low vision differ in the dioptric power obtained.

2. To compare which method (if any) leads to better reading performance by analyzing maximum reading speed, the critical print size (CPS), the MNREAD threshold and the area under the reading speed against print size curve.

Hypotheses of the study

1. There will be a difference in the dioptric power between the reading additions determined by different methods.
2. Reading performance will improve with the addition determined by at least one of the methods compared with no addition.

3.2 General approach

This was an experimental study. Participants were children and young adults with visual impairment. Reading performance was compared between three reading additions obtained with different methods and with no addition, by evaluating the maximum reading speed, critical print size (CPS), area under the reading speed curve and the MNREAD threshold. Clinical tests, including monocular distance visual acuity, contrast sensitivity, cover test, static retinoscopy, subjective refraction and near visual acuity, were performed on all participants. The ocular diagnosis was obtained from the participant's clinical records or, when not available, from their own report. Background information was collected by using a short questionnaire about the current low vision devices that the participant had, if s/he had received any training on the usage of these low vision devices, the time spent on reading each day and their perceived difficulty of reading print of regular size.

An analysis was also conducted to determine if any improvement in reading performance could be predicted by various clinical and demographic factors measured in the study. These factors were distance visual acuity, near visual acuity, contrast sensitivity, lag of accommodation and age.

A sub-analysis included a consideration of factors that might predict the habitual reading performance without any reading addition, as measured by maximum reading speed, critical print size (CPS), area under the reading speed curve and the MNREAD threshold. The factors that were considered as predictive factors were distance visual acuity, near visual acuity, contrast sensitivity, lag of accommodation and age. Another sub-analysis considered which visual factors might predict measures from the questionnaire, i.e., difficulty with reading, time spent reading each day and whether training had been received or not.

The long term goal is to identify a clinical guideline for determining the optimal reading addition for young adults with low vision. This is expected to improve near visual acuity and thus reading performance. If this is found to be the case, it may lead to better school achievement, job options and better performance in daily life activities for these persons.

Chapter 4: Methods

This was an experimental study to compare three methods of determine a reading addition and to determine their effect on reading performance for young adults with visual impairment. Reading performance was evaluated by the maximum reading speed, critical print size, reading acuity threshold and the area under the curve for each participant for a variety of text sizes.

4.1 Inclusion Criteria

- Children and young adults with visual impairment between eight to thirty-five years of age (pre-presbyopic group). There were two subgroups:
    - Those with visual impairment and visual acuity between 6/12 to 6/120 inclusive either monocularly in the better eye or binocularly. The better limit of this was chosen as other studies have defined visual impairment as 6/12 (Tielsch et al. 1990, Gilbert & Ellwein 2008). According to Leat et al. (Leat et al. 1999), visual acuity worse than 6/12 is the level when a person starts to have difficulty in reading and some daily living tasks. The poorer end was chosen as 6/120 according to World Health Organization's definition of low vision (WHO). Acuity poorer than this is defined as legally blind.
    - In order to increase the sample size, a second set of participants with monocular visual loss were included based on the visual acuity of their poorer eye. These

were participants with anisometropic monocular amblyopia reducing the visual acuity in their poorer eye to 6/12 or less, and their poorer eye was used for the study.

- clear enough media so that the retinoscopy reflex can be seen.
- phakic.
- able to read in English because all standard reading materials were written in English.
- no development delays or multiple challenges such as in Down syndrome which would interfere with performing the reading task.
- not taking medication that may affect the participant's normal ocular accommodation.

4.2 Procedure

The ocular diagnosis was taken from the participant's current clinical records. For participants with no clinical records (CNIB participants, n=9), the ocular diagnosis was determined by asking the participant or the participant's parent about his/her ocular diagnosis. Those participants were asked to bring any medical records and/or eyeglasses prescription/s. The majority of them came to the session with their more recent diagnosis/prescription record/s. Other participants and/or parents were aware of their diagnosis which was also consistent with the results findings. The following clinical tests were performed binocularly for participants with visual impairment and monocularly with the best eye occluded for participants with monocular amblyopia:

- Monocular visual acuity was measured with a Bailey Lovie logMAR Chart #5. It consists of fourteen size levels with five letters per line. Acuity was tested at 3 meters. If the participant could not see the largest acuity level, the test distance was reduced to 1.5 meters. Visual acuity was measured with the participant's best optical correction. Visual acuity scoring was done by letter (Bailey et al. 1991), where each single letter was worth a value of 0.02 logMAR.
- The Pelli-Robson contrast sensitivity chart was performed at 1 meter to measure the contrast sensitivity of all participants. By-letter scoring method was used which gives each letter worth a value of 0.05 log units (Elliott et al. 1991). The other aspect of scoring was that if the letter "O" was confused with the letter "C", it was counted as correct (Elliott et al. 1990).
- For the participants with visual impairment, a unilateral cover test was performed to determine the presence of strabismus and, if present, which eye was dominant for the dynamic retinoscopy testing. The dominant eye was considered as the eye with better visual acuity for binocular participants. For participants with monocular vision loss, the eye with the visual loss was chosen for the dynamic retinoscopy testing.
- Static retinoscopy was used as an objective method to measure the participant's refractive error and subjective refraction was performed to refine the results.
- The habitual reading distance was measured with a measuring tape. Participants were asked to hold the Bailey-Lovie near text chart (which was fixed on a clip board), to look at the 1M line and demonstrate their habitual reading distance.
- Near visual acuity was measured with the Bailey-Lovie text chart at 12.5cm which was chosen as the working distance for this research. According to a previous study in our

laboratory, 12.5cm was the most common reading distance for children and young adults with low vision (Leat, personal communication). The smallest sentence that the participant could resolve and read correctly was taken as the near visual acuity of that participant and was recorded in M print units.

All testing was done with the participant's habitual spectacles. If the participant already had a reading addition, the habitual distance prescription was placed in the trial frame without the reading addition. Three methods were used to determine the reading addition for each participant for a reading distance of 12.5cm (8D).

4.2.1 Age method

A reading addition was calculated based on the participant's age and Hofstetter's formula for amplitude of accommodation (Hofstetter 1944) which is that the minimum amplitude of accommodation = 15 – (0.25x age). It was assumed that children, like adults, can exert half of their amplitude of accommodation for reading. This is according to the formula suggested by Leat (Leat 2003) for calculating the reading addition from the person's amplitude of accommodation. This reading addition was determined before the participant's visit for the research session.

The estimated reading addition = working distance (in dioptres) – ½ amplitude of accommodation.

This is a commonly accepted clinical formula and has been shown by Millodot and Millodot (Millodot & Millodot 1989) to be close to what is prescribed for presbyopes. Leat applied this for young persons with low vision (Leat 2003) .

4.2.2 Dynamic retinoscopy method

Dynamic retinoscopy was performed with the modified Nott technique as described in previous studies (Leat & Gargon 1996, McClelland & Saunders 2003, Woodhouse et al. 1993, Leat & Mohr 2007). This method allows a determination of the lag of accommodation. The better eye for participants with visual impairment and the poorer eye for participants with monocular amblyopia (with the other eye occluded) was used for retinoscopy testing. The meridian that required the least accommodative effort which is the least hyperopic meridian (least uncorrected hyperopia or most uncorrected myopia) was used with the distance habitual refractive correction of the participant in place. The participant observed a near target to stimulate accommodation. The near target was an internally illuminated box with high contrast pictures, letters or numbers on each side of the box. The box was fixed on a ruler marked in centimeters with a chin rest which could be moved to a different dioptric distances from the participant (Figure 4:1).

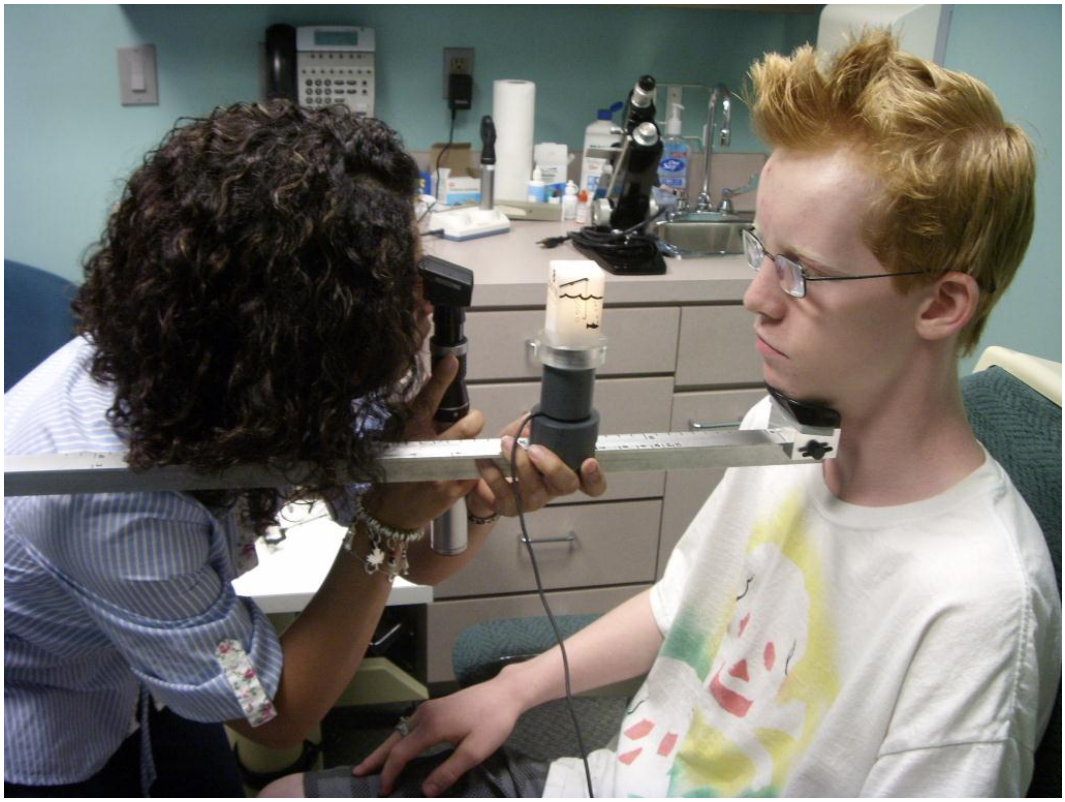

Figure 4:1 Dynamic retinoscopy technique.

Participants were asked to describe the pictures or read the letters/numbers on the box to maintain interest and accommodative effort. The retinoscopist moved closer or further away until a neutral reflex was observed. The lag of accommodation was the distance between the retinoscope sight-hole and the participant's eye. Accommodative response was measured at four different accommodative demands; 4D, 6D, 8D and 10D over the participant's habitual optical correction. If the participant's neutral reflex position fell within the normal limits according to Leat and Mohr's normal age-related data (for 8D) (Leat & Mohr 2007), there was no reading addition determined by the dynamic retinoscopy technique and the reading measurements were undertaken again with no reading addition in place. If the participant's neutral reflex did not fall

within these normal limits, positive lenses were added binocularly in 0.50D steps until the reflex fell within the normal limits. The lowest positive lenses (Leat et al. 1999) which gave rise to a response within the normal range was the reading addition determined by the dynamic retinoscopy technique.

Age-related data for normally sighted subjects from Leat and Mohr's study on accommodative response in pre-presbyopes with low vision (Leat & Mohr 2007) were used in this study to compare with the participants' measured accommodation response (Table 4:1).

Table 4:1 Normal limits of accommodation response for people with normal vision (Leat & Mohr 2007)**.**

Age groups	lower 95% limit of normal in cms				mean of normal in cms			
Demand	4D	6D	8D	10D	4D	6D	8D	10D
6-10 years	30.5	19.3	13.9	11.0	26.8	17.2	12.7	9.9
11-26 years	34.7	23.0	18.4	17	28.3	19.3	15.7	14.5
27-35 years	31.2	21.3	17.8	16.2	26.7	18.2	15.8	14.1

4.2.3 Subjective method

To determine the participant's reading addition subjectively, the Bailey-Lovie text near visual acuity chart was held on a clip-board at 12.5cm and the participant was asked to look at the 1M line. A +1.00DS was introduced binocularly (for participants with visual impairment) or monocularly (for participants with monocular vision loss) over the habitual spectacles and the participants were asked to compare between the +1.00DS and without the lens and pick the lens that led to a sharper and clearer image. If the participant preferred the extra lens it was incorporated into the trial frame and another +1.00D lens was shown. The process was repeated until there was no further subjective improvement. Then it was refined in +/-0.50DS steps. The end point was achieved subjectively when the participant reported that the extra lens (+ or -0.50DS) did not make the image clearer or it was the same as with the previous lens The subjective addition was the least plus lens that resulted in the best clear image.

4.3 Reading charts

Reading charts for this research were made from standardized sentences supplied by Legge which are similar to the standardized MNREAD charts (Legge 2007). MNREAD standardized sentences charts are continuous text reading charts for normal and low vision observers printed in a sequence of decreasing print size. Each sentence had between 9 to 15 words and consisted of three lines of the same length. They were printed in Times New Roman font. The charts had print sizes in a logMAR scale and their range was from 1.3 logMAR to -0.4 logMAR (8M to 0.16M) in 0.1 logMAR steps. Eight different sets were made and each set had 18 sentences in a grade 3 difficulty. The sentences were arranged in a way that no sentence was

repeated by any participant. They were printed on semi-gloss Canon paper by an *i*990 Canon printer at the maximum resolution of 4800x2400 dpi.

The sizes of the sentences had been previously calibrated in the following manner. The size of a lower case "x" was measured and the M print was calculated as height/0.01454 and logMAR for a 40cms distance was calculated as log10(687.5xheight/40) (Legge 2007). For smaller print sizes, the size of a whole word or sentence was used and this was proportionally scaled to the size of the "x" by measurement of larger print. For viewing at 12.5 cms, the logMAR was calculated by adding 0.505 to the logMAR at 40cms.

4.4 Procedure

All sentences were covered with strips of white paper. They were all covered and each sentence was uncovered in turn before the participant started to read.

A demonstration set of sentences was used to demonstrate the task and to determine the approximate MNREAD threshold of the participants with their habitual spectacles at the 12.5 cm distance. Normal room lighting was used and extra lighting was demonstrated and used if preferred by the participant. Lighting was kept constant for each participant for the whole research session. The demonstration set text size range was between 1.3 logMAR to -0.2 logMAR (8M to 0.26M). The participants were asked to read as far as they could. The last sentence that the participant read correctly was the approximate threshold of that participant.

After determining the three reading additions, participants were asked to read the reading charts in a random order with the three reading additions powers and without a reading addition.

Randomization was done in advance for both reading additions and the sets of the reading charts. The reading addition was taped onto the participant's habitual glasses. If he/she did not have spectacles, the lenses were placed in a trial frame. Two sets of reading charts were used for each reading addition and without a reading addition and the reading speeds for each size of print were averaged.

The experimenter started at 8 levels above the approximate threshold sentence (Lovie-Kitchin et al. 2001), as measured above, and moved onto each subsequent sentence in decreasing print size in order until the participant read more than 50% of the sentence wrong or could not read any words in the sentence. The previous study from our lab indicated that starting 8 levels above the approximate threshold ensured that there was a reading speed plateau with a clear point where the reading speed started to decrease as the text size got smaller and it is also in agreement with the study of Lovie Kitchin et al. (Lovie-Kitchin et al. 2001). Sentences were covered before the participant started reading and participants were asked to start reading out loud as soon as the sentence was uncovered. They were instructed to read as quickly as possible, but without sacrificing accuracy. If they did make a mistake, they were asked not to correct themselves. Charts were fixed on a clip-board and a thread of 12.5cm was attached to the clip board to measure the reading distance and keep it constant (Figure 4:2).

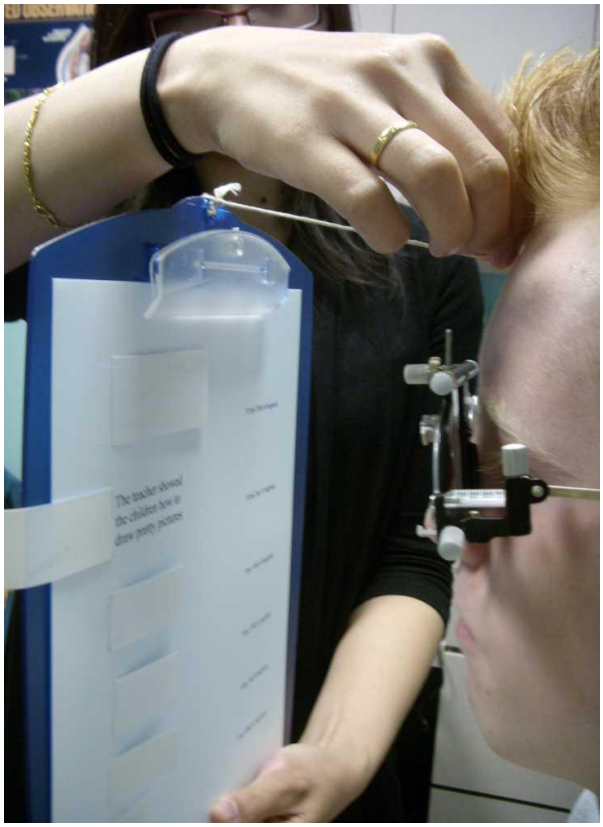

Figure 4:2 Placing the charts and keeping the distance constant.

The author positioned the reading lenses and controlled the position of the text. Note that the participants were not allowed to hold the text themselves, as they would be likely to change the working distance. The participants were timed with a stop watch from the moment he/she read the first word of the sentence to the moment he/she read the last word of the sentence chart and the errors were recorded (Legge 2007). The timing and recording of errors was undertaken by a person who was naïve to the reading addition used. He/she marked every word that was read incorrectly and noted the total time needed to read each sentence in seconds.

4.5 Analysis of MNREAD sentences

4.5.1 Reading speed and Critical print size (CPS)

Reading speed in correct words per minute (CWPM) was calculated by counting the correct words that were read and the time taken to complete the sentence in seconds. Reading speed for each print size was given by:

Reading speed = number of correct words / time in minutes (Legge 2007)

The CWPM for each print size of the two charts was averaged. The averaged reading speed was plotted as a function of print size. The plot is expected to show a reading speed plateau of approximately constant reading speed across the larger print sizes and a drop in reading speed as the print size gets smaller than the CPS (Legge 2007) (Figure 4:3)

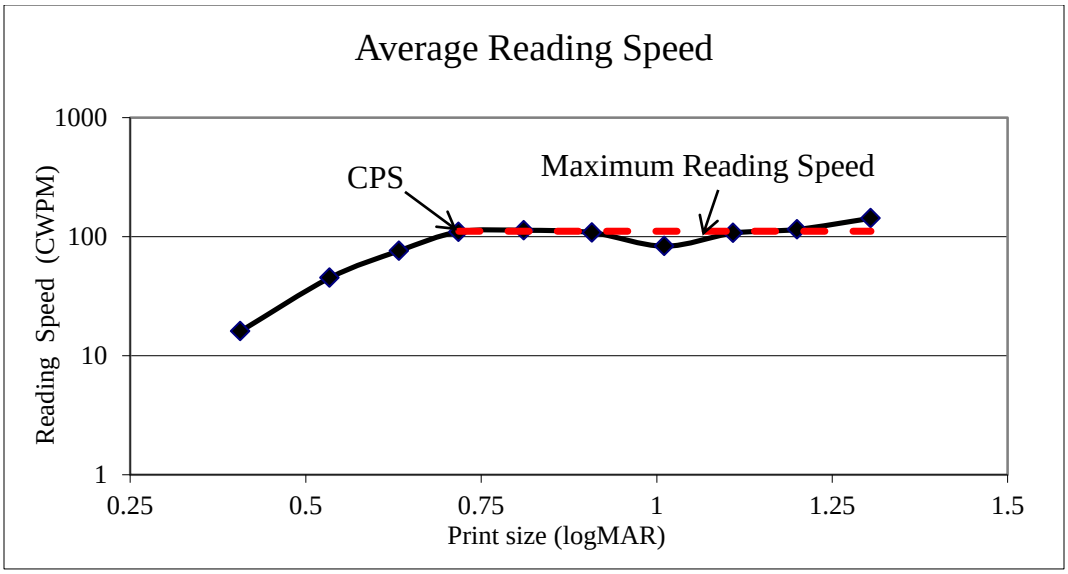

Figure 4:3 Hypothetical example of maximum reading speed and CPS. Dashed line is the maximum reading speed.

The plateau and CPS were determined by an iterative process (Legge 2007). The mean and the standard deviation of the highest data point (logarithm of the highest reading speed) and the two adjacent points were calculated. The lower 95% range was calculated by the mean minus 1.96 x SD (Legge 2007) to check which data points of reading speed fell within the 95% range. All other points falling within this range were then included and used to recalculate a new mean and 95% range as above (Lussenhop & Corn 2002). These calculations were repeated until no other points fell within the new range. If an intermediate point fell out of the range, it was still included in the calculation of maximum reading speed. The smallest print size that was included in the plateau was the critical print size (CPS) and the final maximum reading speed was the average of all reading speeds that fell within the reading speed plateau (Legge 2007) (Figure 4:4).

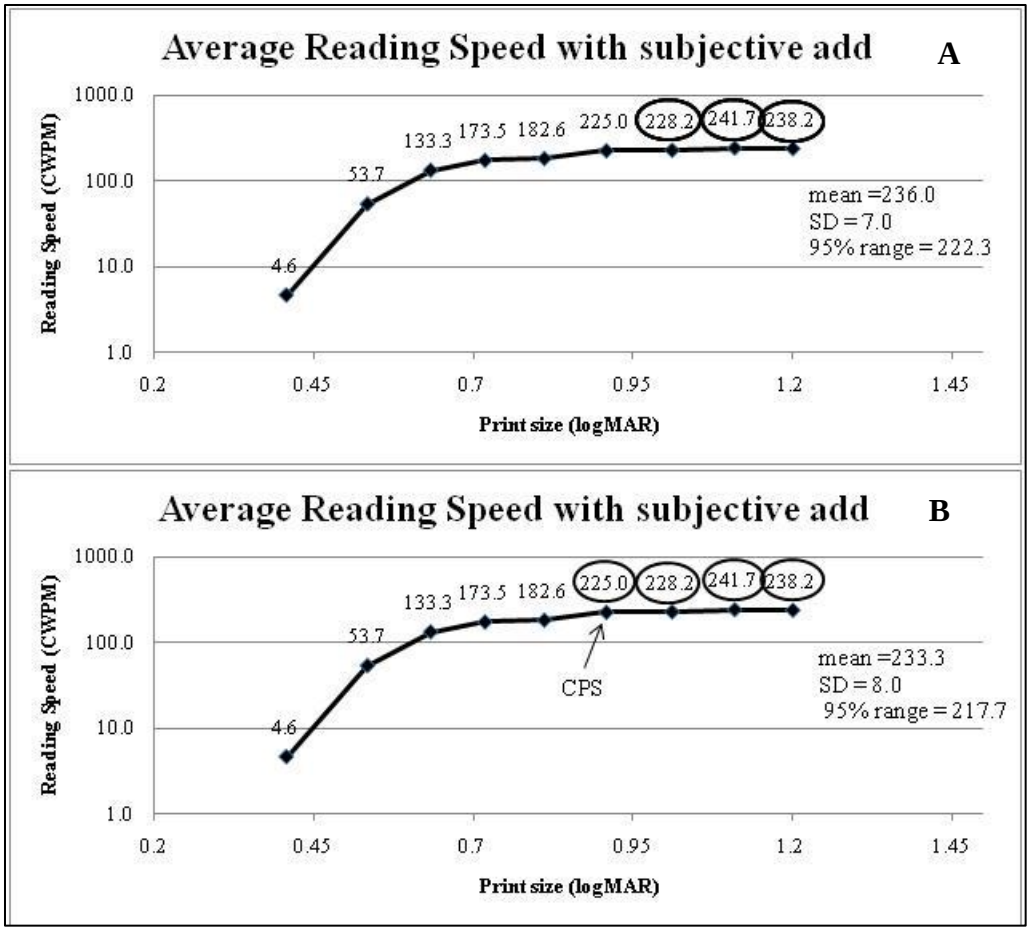

Figure 4:4 An example of Maximum reading speed and CPS calculation. A. mean and 95% range of initial 3 points. B. recalculation with an additional point that fell within the range.

4.5.2 Area under the curve

The area under the curve was calculated by transforming the reading speed into log units and adding the geometrical areas under each pair of data points across the curve. Between each pair of points the triangle and rectangle area were calculated (Figure 4:5). The area under the curve was taken as the sum of all the triangles and rectangles between all the points.

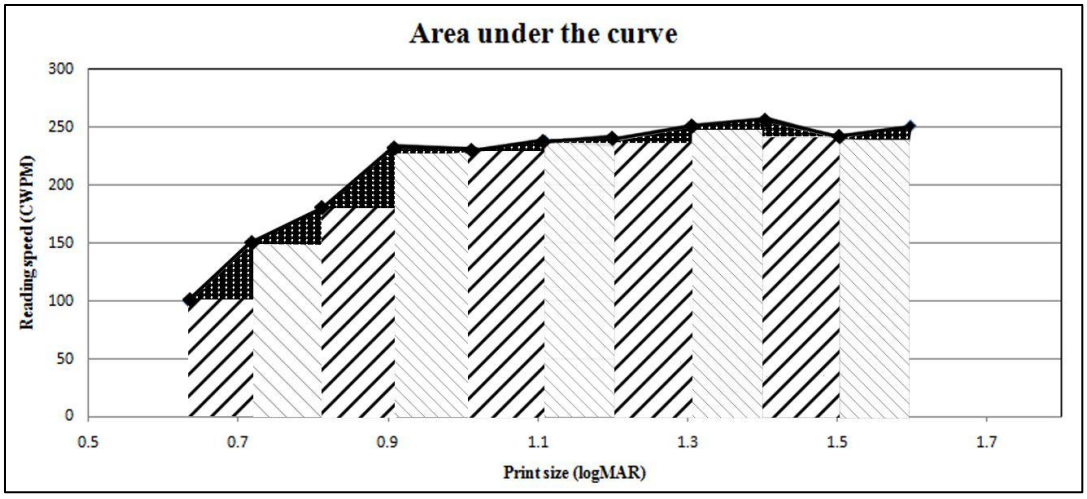

Figure 4:5 Calculation of the area under the curve showing the sections with the triangles and rectangles highlighted.

4.5.3 MNREAD acuity threshold

MNREAD acuity threshold was calculated by counting the words that were read incorrectly for each sentence (Figure 4:6). This method is similar to the letter-by-letter method that is used for distance visual acuity (Bailey et al. 1991). For each sentence, the number of errors that were made by the participant was divided by the total number of words for each sentence and multiplied by 0.1 which is the difference between the print sizes. In other words, a proportion of incorrect words for each sentence was calculated and each sentence was weighted as 0.1 logMAR. The total number for errors that were made for each chart and the smallest print size that the participant attempted to read gave the reading acuity threshold, as follows:

Reading acuity threshold = smallest print size attempted + (0.1 x total number of errors as a proportion of the number of words at each level) (Legge 2007).

Subject name _____

With add / Dynamic ret. Add / Subjective add / Age add

	8M, 1.3 logMAR (12 words) He could see a bird outside if he looked through his window Time ___5.56__ mins Correct words ___12___ Number of errors __0___	**6.3M, 1.2 logMAR (12 words)** You should not ride your bike down the middle of the street Time ___6.12____ mins Correct words __12____ Number of errors __0___	
	4.9M, 1.1 logMAR (10 words) Everyone wanted to go outside when the rain finally stopped Time ___6.88___ mins Correct words ___10___ Number of errors __0___	**4M, 1.0 logMAR (11 words)** They were not able to finish playing the game before dinner Time ___7.74___ mins Correct words ___11___ Number of errors __0___	
2/12*(0.1)= 0.016	**3.2M, 0.9 logMAR (12 words)** Many people came to ~~help~~ us clean the place ~~after~~ the party Time ___9.46___ mins Correct words __10___ Number of errors __2___	**2.5M, 0.8 logMAR (11 words)** The women met on the ~~street and~~ talked ~~about their~~ children Time ___11.22____ mins Correct words __7___ Number of errors __4__	4/11*(0.1)= 0.036
9/13*(0.1)= 0.069	**2M, 0.7 logMAR (13 words)** His blue ~~hat was~~ on ~~the table before we~~ ~~went out~~ for ~~dinner~~ Time ___13.42__ mins Correct words __4___ Number of errors __9__	**1.6M, 0.6 logMAR (12 words)** The ring looks very pretty on her finger and you look happy Time _____ mins Correct words _____ Number of errors _____	

MNREAD threshold= 0.7 + 0.121 = 0.821 logMAR

Figure 4:6 An example of MNREAD threshold calculation

4.6 Recruitment

A search was conducted in the Low Vision Clinic at the School of Optometry at University of Waterloo to find potentially eligible participants. Their files were reviewed to check for eligibility and to check if consent to be contacted regarding research studies was included. If so, an information letter was mailed and a week later they were contacted to see if they were willing to take part. If so, an appointment was scheduled at the School of Optometry. Those who were only seen more recently than February 2007 were contacted by a staff member who was independent of the study, who asked if they were willing to be contacted about participation. If so, the same letter was mailed.

A colleague at the Vision Institute of Canada was given the criteria of the study and searched in their clinic files for eligible participants. They were contacted by phone by a professional staff or a final year optometry intern to see if they were willing to take part. If so, they were mailed an information letter and contacted a week later to schedule an appointment at the Vision Institute of Canada clinic in Toronto. For participants who were recruited from the Canadian National Institute for the Blind (CNIB), a search was conducted in the paper files to look for eligible participants. They were mailed a similar information letter and contacted a week later to schedule an appointment at the CNIB office in Toronto.

4.7 Sample Size

The sample size was estimated from previous data from our laboratory based on the standard deviation (SD) of the differences between the reading addition estimated by age and the reading addition found by dynamic retinoscopy, which was 2.087. Power was set to 80% and the

p value = 0.05. The effect size was chosen to be +1.00DS which was considered a clinically significant difference in reading addition for this population. Taking these values the sample size was estimated at 37 participants.

4.8 Statistical tests

Analysis of the data was done using the statistical and Graphical Software (SYSTAT 13) and Microsoft Excel. The level of significance for all tests was 0.05. Repeated measures of analysis of variance (ANOVA) was used to show any differences in reading performance between the three different reading additions and no addition. This was performed for maximum reading speed, critical print size, area under the reading speed curve (log) and MNREAD threshold. Post hoc testing with Bonferroni correction was used to determine where any differences lay, if a significant main effect was obtained. A forward multiple step-wise regression analysis with 0.05 to enter and 0.15 to remove was conducted to study the association between visual factors that may predict reading performance or an improvement in reading performance. Pearson correlation was used to determine any association between measured visual factors and reading performance. Spearman correlation was used to study any correlation between difficulty of reading and time spent on reading each day and reading performance.

The study was approved and received full ethics clearance from the Office of Research Ethics, University of Waterloo.

Chapter 5: Results

5.1 Subjects

Thirty participants were recruited from the low vision clinic at the School of Optometry at University of Waterloo (n=14), the Canadian National Institute for the Blind in Toronto (CNIB) (n=9) and the Vision Institute of Canada in Toronto (n=7). Participants were between the ages of 9 to 32 years (mean 16 ± 6.0 years). See Figure 5:1 for the distribution of ages.

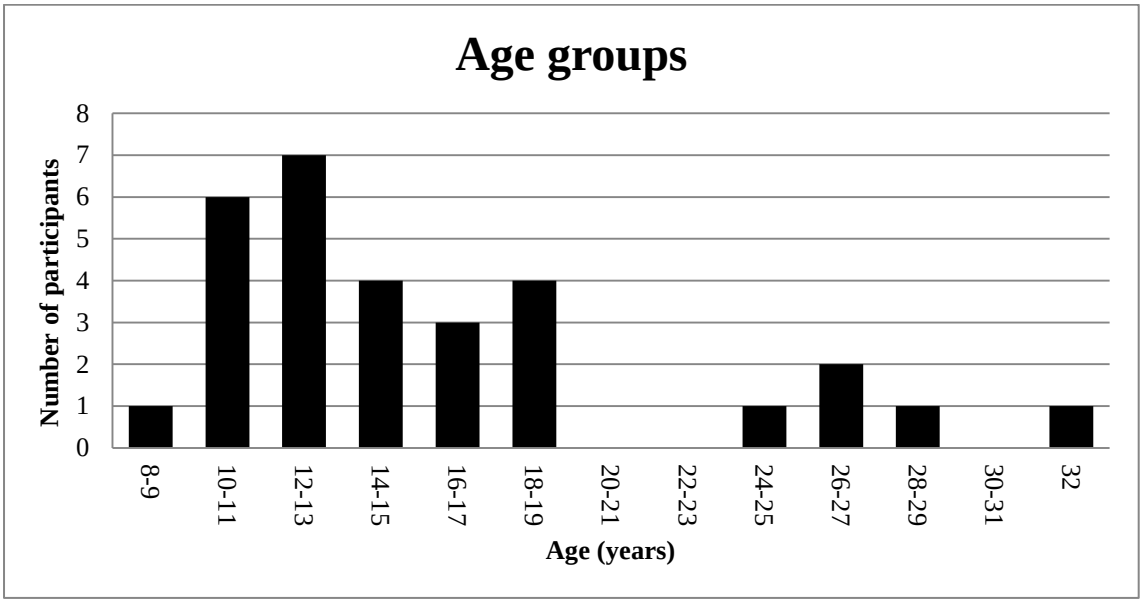

Figure 5:1 Age of participants.

There were equal numbers of males and females. Distance visual acuity of the tested eye ranged between 0.357 to 1.184 logMAR with a mean of 0.797 ± 0.220 logMAR. Six participants

had a reading addition. The most common causes of low vision across participants were nystagmus (50%) and albinism (20%). A summary of participants is shown in Table 5:1.

Table 5:1 Demographic details of participants

Subject	Age (y)	Diagnosis	VA of eye tested (logMAR)	Eyes tested Binocular or Monocular	Accommodation within normal range @ 12.5cm	Rx of tested eye	Habitual Add (D)
1	11	Peter's Anomaly	0.4	monocular	no	+2.00-1.00x7	+1.00
2	11	Ocular Albinism	0.6	binocular	yes	+6.00-2.00x180	
3	32	Optic nerve hypolasia, pendular nystagmus	0.8	binocular	no	+0.50-0.50x90	+3.00
4	17	Bilateral asymmetrical optic nerve, foveal hypolasia, nystagmus	0.66	monocular	no	+3.00-0.75x10	
5	15	Left optic nerve hypoplasia, anisometropia	0.05	binocular	no	-3.50-3.00x90	
6	26	Retinopathy of prematurity, retinal detachment, high myopia, nystagmus	0.88	binocular	no	-20.25DS	
7	26	Paramacular retinal scaring	0.84	monocular	yes	-2.00-0.75x60	+3.00
8	14	Albinism, nystagmus	0.56	binocular	yes	+4.00-2.00x180	

Table 5:1 cont. Demographic details of participants

Subject	Age (y)	Diagnosis	VA of eye tested (logMAR)	Eyes tested Binocular or Monocular	Accommodation within normal range @ 12.5cm	Rx of tested eye	Habitual Add (D)
9	19	Albinism, nystagmus	0.82	binocular	no	+4.00-2.00x180	
10	13	Optic nerve atrophy, retinal detachment,	1.1	binocular	no	-21.00-0.50x160	
11	13	Coloboma	1	binocular	no	-1.25-0.75x180	
12	10	Amblyopia OD, right esotropia	1	monocular	no	+5.75-0.50x5	
13	14	Familial exudative vitreoretinopathy, glaucoma, retinal detachment	0.9	monocular	no	-14.25-1.50x35	
14	10	Familial exudative vitreoretinopathy	0.98	binocular	no	-11.00-1.00x65	
15	19	Stargardt's disease	1.102	binocular	yes	PL	
16	25	Ocular albinism	0.781	binocular	yes	+4.25-4.25x5	
17	9	Persistent hyperplastic primary vitreous	0.802	monocular	no	PL-1.50x125	
18	11	Albinism, nystagmus	0.821	binocular	no	+4.00-2.00x95	
19	16	Nystagmus	1.028	binocular	no	PL-1.00x80	
20	16	Achromatopsia ,nystagmus	1.02	binocular	no	-7.00-1.25x5	
21	13	Congenital nystagmus	0.642	binocular	yes	+1.75-0.25x180	
22	12	Retinoschisis	0.841	binocular	yes	-0.50	

Table 5:1 cont. Demographic details of participants

Subject	Age (y)	Diagnosis	VA of eye tested (logMAR)	Eyes tested Binocular or Monocular	Accommodation within normal range @ 12.5cm	Rx of tested eye	Habitual Add (D)
23	19	Congential nystagmus, optic atrophy	0.833	binocular	yes	+2.50-4.00x170	
24	12	Amblyopia OS, hyperopic anisometropia	1.184	monocular	no	+5.75-1.50x35	
25	12	Congential nystagmus	0.52	binocular	yes	+0.75-3.50x150	+1.50
26	13	Aniridia, , nystagmus	0.863	binocular	yes	-7.00-3.50x180	
27	29	Albinism, nystagmus	0.622	binocular	no	+3.00-3.25x24	+3.50
28	18	Cone dystrophy, high myopia	0.98	binocular	no	-12.00-1.50x5	
29	11	Oculocutaneous albinism nystagmus	0.48	binocular	yes	+0.75-1.00x165	+2.75
30	14	Oculocutaneous albinism nystagmus	0.658	binocular	yes	+5.25-0.75x10	

Optimum acuity reserve was calculated as the difference between the logarithm of the critical print size and MNREAD threshold (Cacho et al. 2010, Kartha 2010). Acuity reserves showed large individual variations across participants. It ranged between 0.02 to 0.48 log units (1X to 3X). The mean acuity reserve required by the participants was 0.22 logMAR (1.7X). Thirty-six percent (11/30) of the participants needed between 0.2 to <0.3 log (1.6X to <2X) as an acuity reserve. A histogram of the acuity reserves is shown in Figure 5:2.

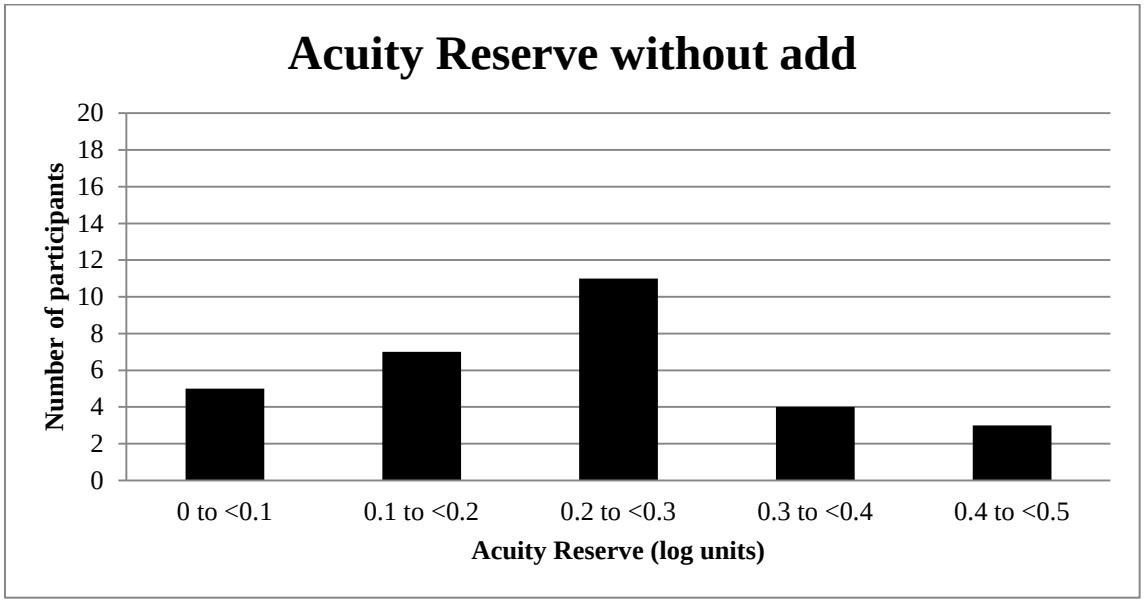

Figure 5:2 Histogram of acuity reserve across participants. Acuity reserve was calculated as the difference between the logarithm of the critical print size and MNREAD threshold.

More information about the participants was collected from a short questionnaire (see Appendix A for the full questionnaire). This included questions about their habitual low vision devices and if they were trained in how to use them. Questions were also asked about the time

spent reading each day and the difficulty of reading print of regular size. The questionnaire was not undertaken for participants with monocular amblyopia, who would not have low vision devices.

The most common low vision devices were closed circuit televisions (CCTV) followed by hand-held magnifiers. A bar chart of the all the low vision devices that were used by the participants is shown in Figure 5:3.

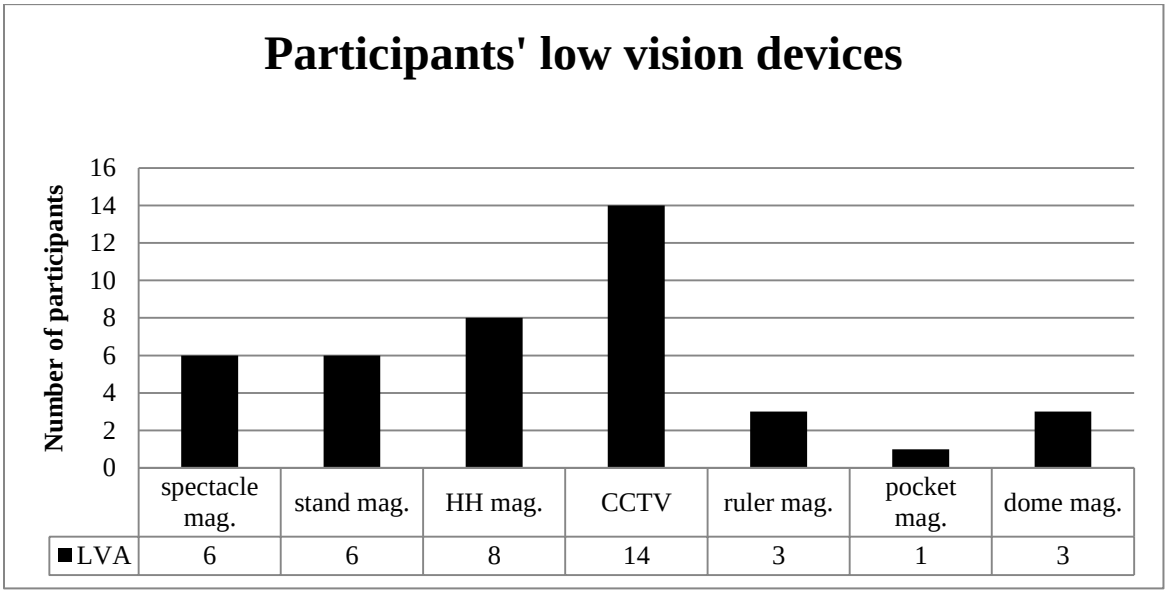

Figure 5:3 Bar chart of the participant's low vision devices. HH = hand held magnifier, CCTV = closed circuit TV.

Forty two percent (11/26) of the participants reported they did not receive any training on the usage of their low vision aids. A pie chart showing whether the participants attended any training sessions on the usage of their low vision devices can be seen in Figure 5:4.

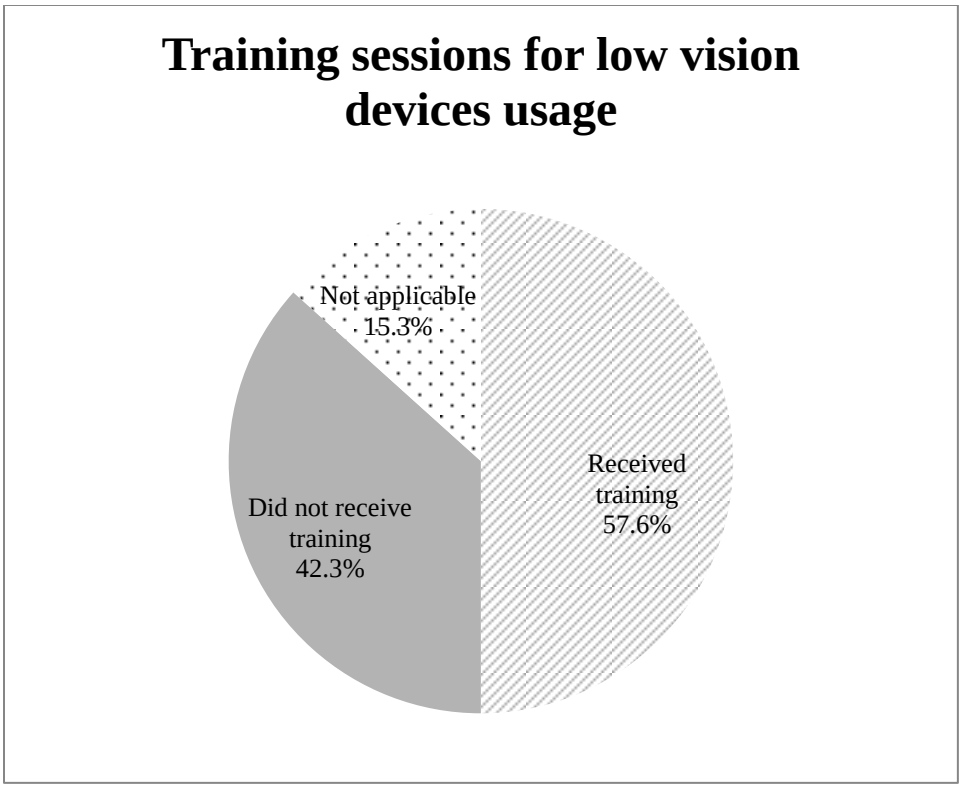

Figure 5:4 Pie chart showing number of participants who received or did not receive training.

The time spent on reading each day was collected by asking participants about their frequency of reading. The most frequent answers given was that they read between 30 minutes to two hours and two hours to four hours each day. The time reported spent on reading each day is shown in Figure 5:5.

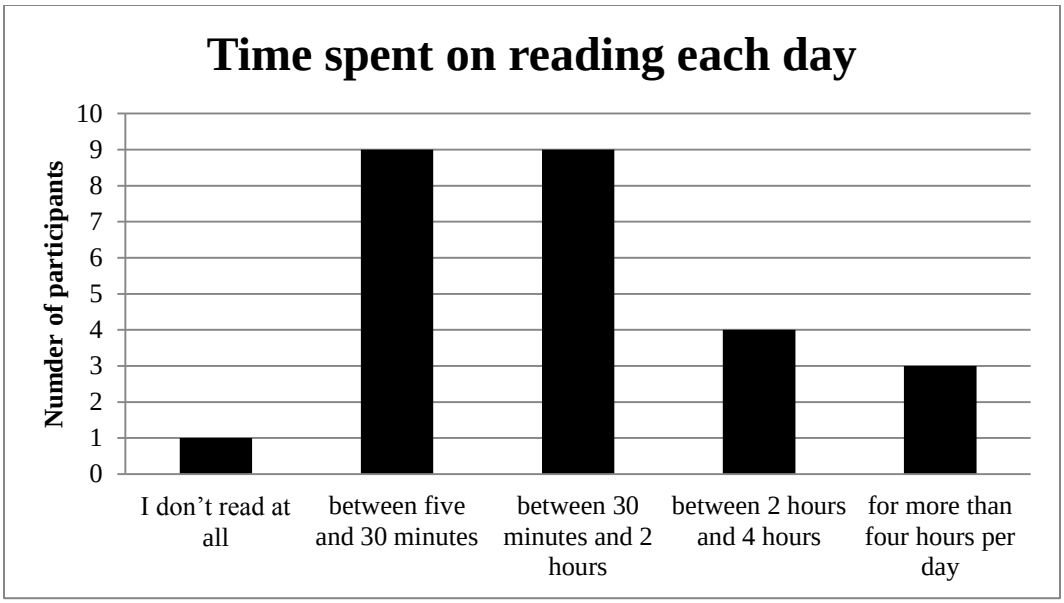

Figure 5:5 Bar chart showing the time that the participants reported that they spent reading each day.

Participants were also asked about the perceived difficulty of reading material of regular print size. The majority of the participants had little difficulty reading print of regular size. Figure 5:6 shows the perceived difficulty of reading regular size print across participants.

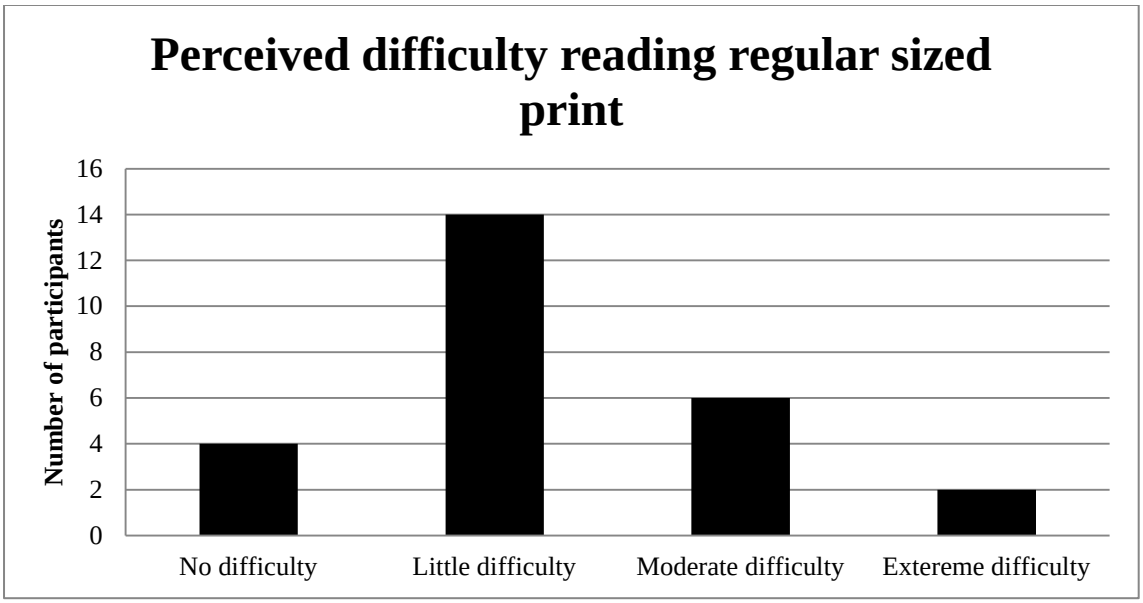

Figure 5:6 Bar chart showing the perceived difficulty of reading regular sized print.

5.2 Reading additions powers and performance with reading additions – whole group

The reading addition that was determined by dynamic retinoscopy ranged between 0.50 to 7.00 D (mean of 1.40 ± 1.69). The reading addition determined by the subjective method ranged between 0.50 to 7.00 D (mean of 2.25 ± 1.44). The reading adding that was determined based on the participant's age ranged between 1.50 to 4.75 D (mean 2.64 ± 0.81).

A repeated measures ANOVA (3x reading additions) was conducted on the dioptric power of the three reading additions. There was a significant difference between the three reading additions powers in dioptres that were determined by the three different methods ($F=7.568$, $p=0.001$). Post hoc comparisons using Bonferroni correction for multiple comparisons indicated that the age addition (mean 2.46 ± 0.81) was significantly higher than the dynamic retinoscopy addition (mean 1.40 ± 1.69, $p=0.002$). Also, the subjective addition (mean 2.25 ±

1.44) was significantly higher than the addition that was determined by the dynamic retinoscopy technique (mean 1.40 ± 1.69, p=0.038). There was no difference between the age addition and the subjective addition, p>0.05 (Figure 5:7). All reading additions were significantly greater than zero (t-test <0.0005).

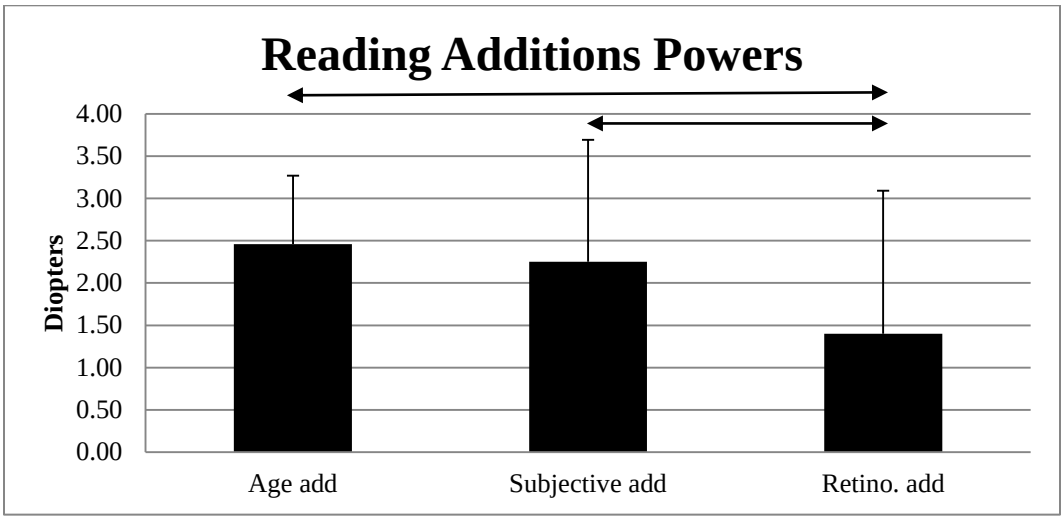

Figure 5:7 Reading additions determined by three different methods. Arrows show those that were significantly different at the p=0.05 level. Error bars indicate ±1 SD.

Repeated measures ANOVA (4x [no addition + 3 reading additions]) considering maximum reading speed (Figure 5:8), MNREAD threshold (Figure 5:9), critical print size (CPS) (Figure 5:10) and the logarithm of the area under the reading speed curve (Figure 5:11) showed that there was no significant difference in reading performance for any of these measures with any of the reading additions or between each of these reading additions and no addition (p>0.05).

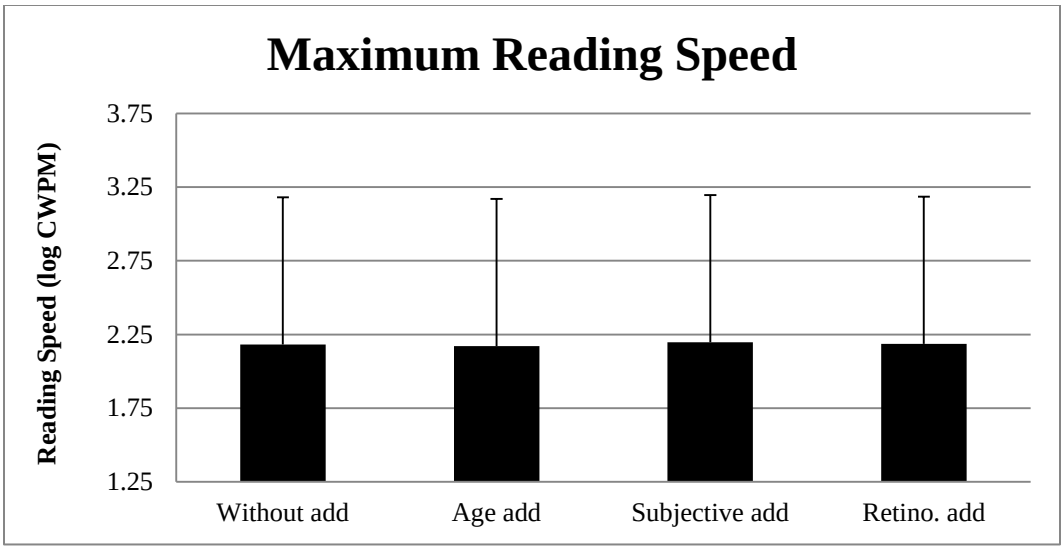

Figure 5:8 Maximum reading speed (log) with three reading additions and with no addition. Error bars indicate ±1 SD.

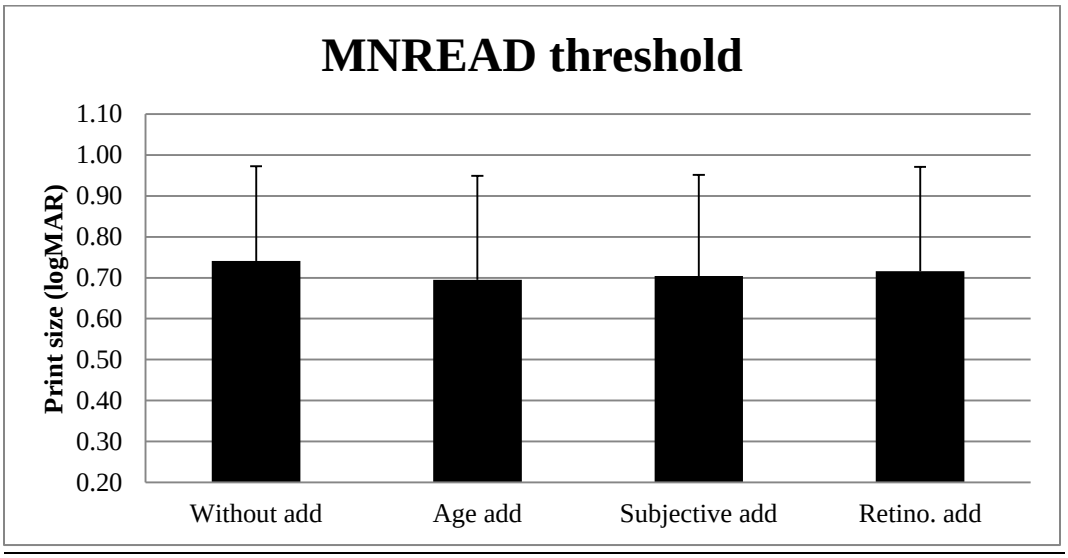

Figure 5:9 MNREAD threshold (logMAR) with three reading additions and with no addition. Error bars indicate ±1 SD.

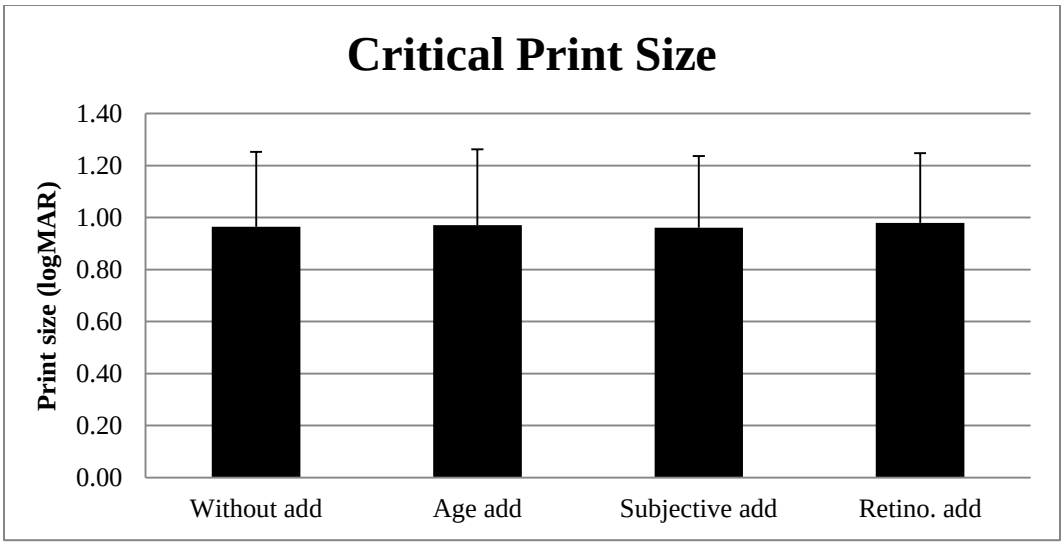

Figure 5:10 Critical print size (logMAR) with three reading additions and with no addition. Error bars indicate ±1 SD.

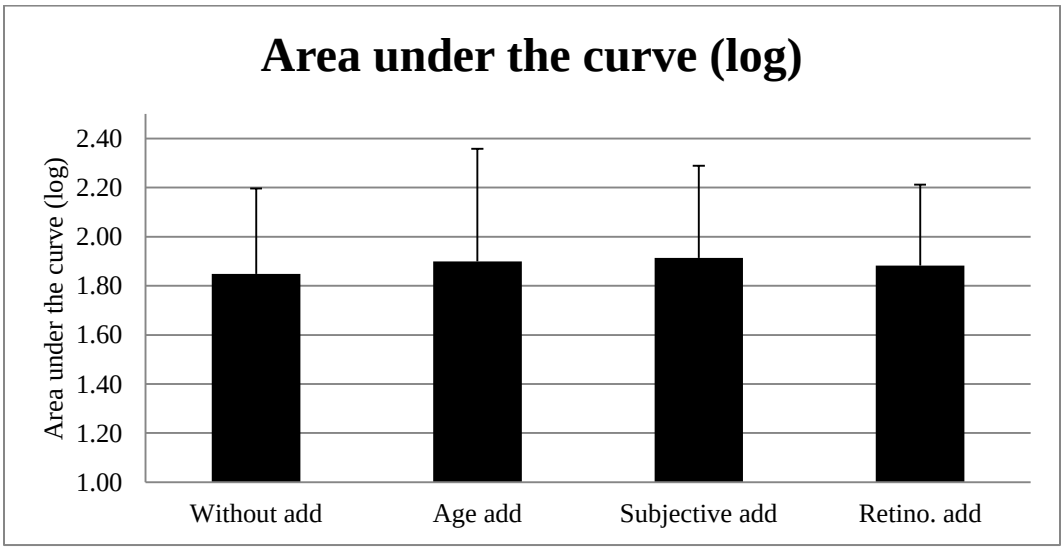

Figure 5:11 The logarithm of the area under the reading speed curve with three reading additions and with no addition. Error bars indicate ±1 SD.

From Figure 5:1 it can be seen that there were two distinct groups, according to age. As there may have been a different pattern with respect to age, a separate analysis was conducted on the younger group of the participants aged between 8 to 18 years old (it was not possible to do this for the older group, as there were insufficient numbers). A repeated measures ANOVA (3x reading additions) was conducted on the dioptric power of the three reading additions. There was a significant difference between the three reading additions powers in dioptres that were determined by the three different methods ($F=7.201$, $p=0.002$). Post hoc comparisons using t-tests with Bonferroni correction for multiple comparisons indicated that the age addition (mean 2.00 ± 0.3) was significantly higher than the dynamic retinoscopy addition (mean 1.00 ± 1.00, $p=0.0003$). Also, the subjective addition (mean 1.90 ± 1.50) was significantly higher than the retinoscopy addition (mean 1.00 ± 1.00, $p=0.007$). This is the same as for the group as a whole.

Repeated measures ANOVA (4x [no addition + 3 reading additions]) considering maximum reading speed, MNREAD threshold, critical print size (CPS) and the logarithm of the area under the reading speed curve showed that there was no significant difference in reading performance for any of these measures with any of the reading additions or between each of these reading additions and no addition ($p>0.05$). Again, this is the same as for the whole group.

5.3 Reading additions and performance of reading additions – participants with normal accommodation excluded

Repeated measures ANOVA was conducted on the whole group excluding the twelve participants who had normal accommodation at the 12.5 cms distance and who therefore did not require a reading addition determined by the dynamic retinoscopy technique (i.e. the reading addition determined by dynamic retinoscopy was zero). This analysis was done as it may also be expected that there would be no need for an addition of any kind, due to their normal accommodation.

Repeated measures ANOVA (3x reading additions) considering reading additions powers showed that there was no significant difference in the three reading additions. Although there was no difference between the power of the reading additions, all the additions were significantly greater than zero (t-test <0.0005).

Repeated measures ANOVA (4x [no addition + 3 reading additions]) showed a significant difference in the logarithm of the area under the reading speed curve ($F=3.087$, $p=0.035$). Post hoc testing applying the Bonferroni correction showed that the area under the curve was greater with the subjective addition (mean 1.92 log ± 0.36) than with no reading addition (mean 1.79 log ± 0.35) ($p=0.048$) (Figure 5:12).

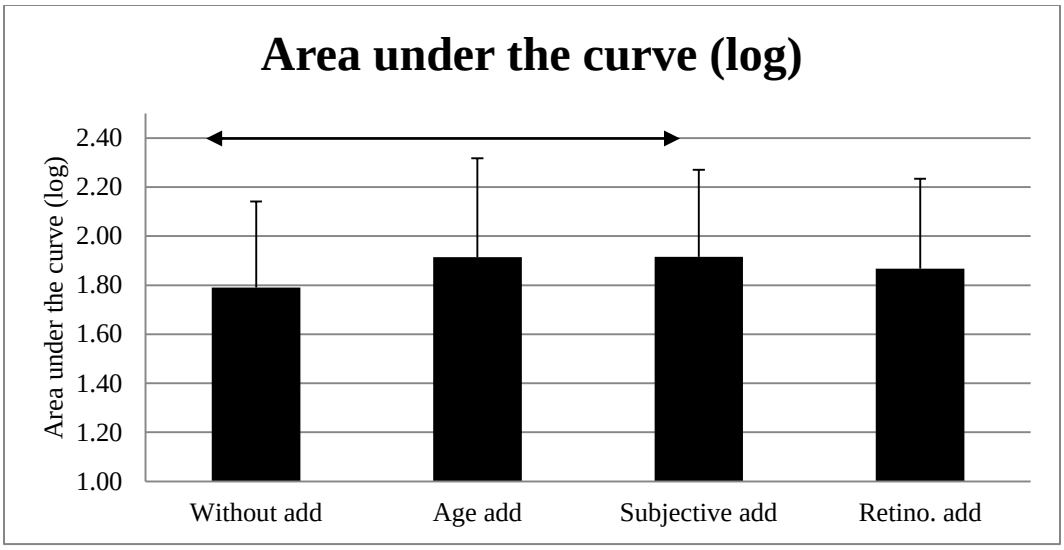

Figure 5:12 The logarithm of the area under the reading speed curve determined by three different methods (excluding participants with normal accommodation). Arrow shows significance at the p=0.05 level. Error bars indicate ±1 SD.

ANOVA (4x [no addition + 3 reading additions]) also showed a significant difference in the MNREAD threshold (F=3.347, p=0.026). Post hoc testing showed that the MNREAD threshold was lower (better) with the age add (mean 0.730 ± 0.248) than with no reading add (mean 0.800 ± 0.236) (p=0.012) (Figure 5:13).

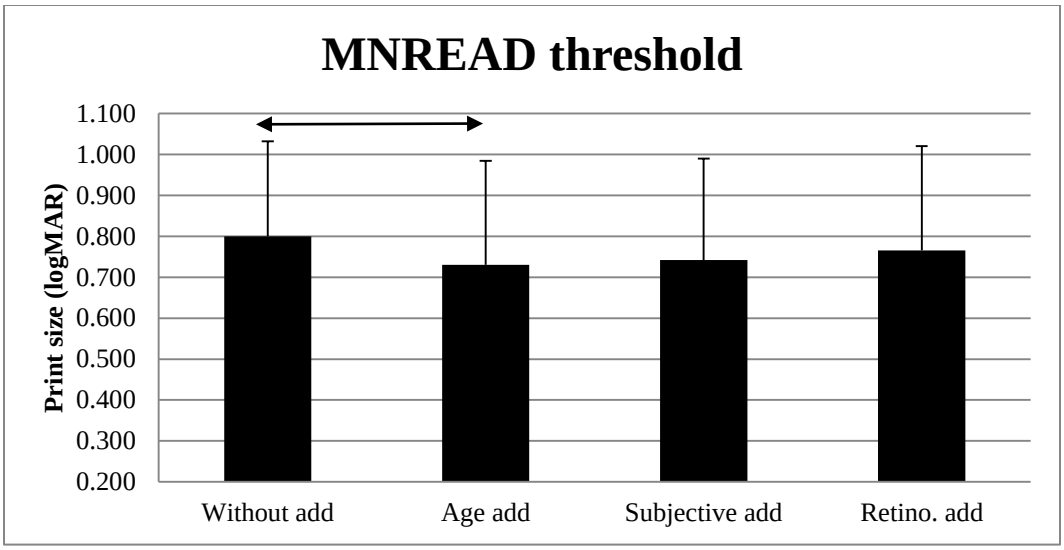

Figure 5:13 MNREAD threshold calculated for the three different additions (excluding participants with normal accommodation). Arrow shows significance at the p=0.05 level. Error bars indicate ±1 SD.

Repeated measures ANOVA (4x [no addition+3 reading additions]) considering maximum reading speed and critical print size (CPS) showed that there was no significant difference in reading performance for either of these measures with any of the reading additions or between any reading addition and no addition ($p>0.05$).

An analysis of the younger group with abnormal accommodation was not possible, as the numbers of participants was too reduced (only 12 were under 18 and had abnormal accommodation)

In this study, spectacle accommodation was measured i.e. from the spectacle plane, as it was considered that measures of spectacle accommodation response are what are relevant from the standpoint of functional vision. However, the ocular demand would be significantly different

for participants with high refractive errors. For a given stimulus distance, people with high hyperopia will have a higher ocular demand and people with high myopia will have a lower ocular demand (Rabbetts 1998) . In this study, all the participants who had high refractive errors (>6D) were myopes. A calculation of the ocular accommodation response and the actual ocular demand was conducted for the meridian with the highest refractive error. Since the ocular demand did not match exactly with any of the standard working distances for which there is control data, the lag of the accommodation was calculated and compared with the normal lag for the most similar stimulus distance (4D, 6D or 8D). This calculation showed that all the participants remained in the same group in terms of whether they had normal or abnormal accommodation as the original designation.

Thus there was evidence of an overall improvement in reading performance with the subjective addition and the age addition. It was also noted that there was considerable variability between participants, some showing an apparent definite improvement while others not doing so. Figures 5:14 – 5:17 are examples of participants showing an improvement in reading performance with reading additions.

In the first example (Figure 5:14) there was a definite improvement with all reading additions in all the measures of reading performance, i.e., maximum reading speed, critical print size, the logarithm of the area under the reading speed curve and MNREAD threshold. The second example (Figure 5:15) seems to show an improvement with all reading additions in critical print size, the logarithm of the area under the reading speed curve and MNREAD threshold but not in maximum reading speed. The third example (Figure 5:16) shows an improvement in maximum reading speed, the logarithm of the area under the reading speed curve and MNREAD threshold with the subjective addition and the age addition. In the fourth

example (Figure 5:17), the participant showed a large improvement in reading performance with the age addition.

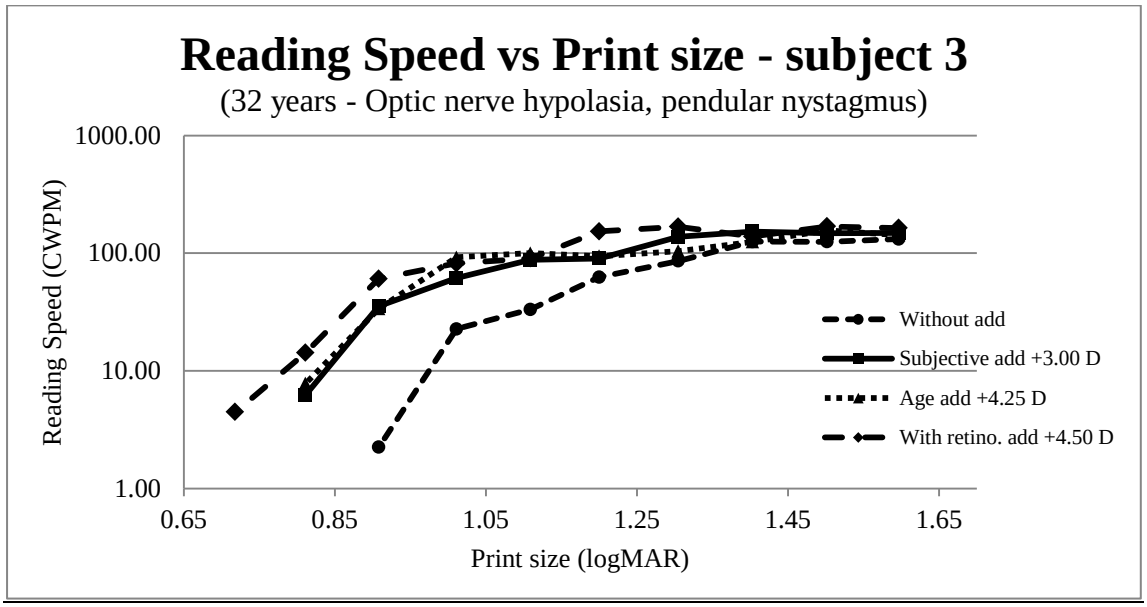

Figure 5:14 Reading speed against print size for participant 3.

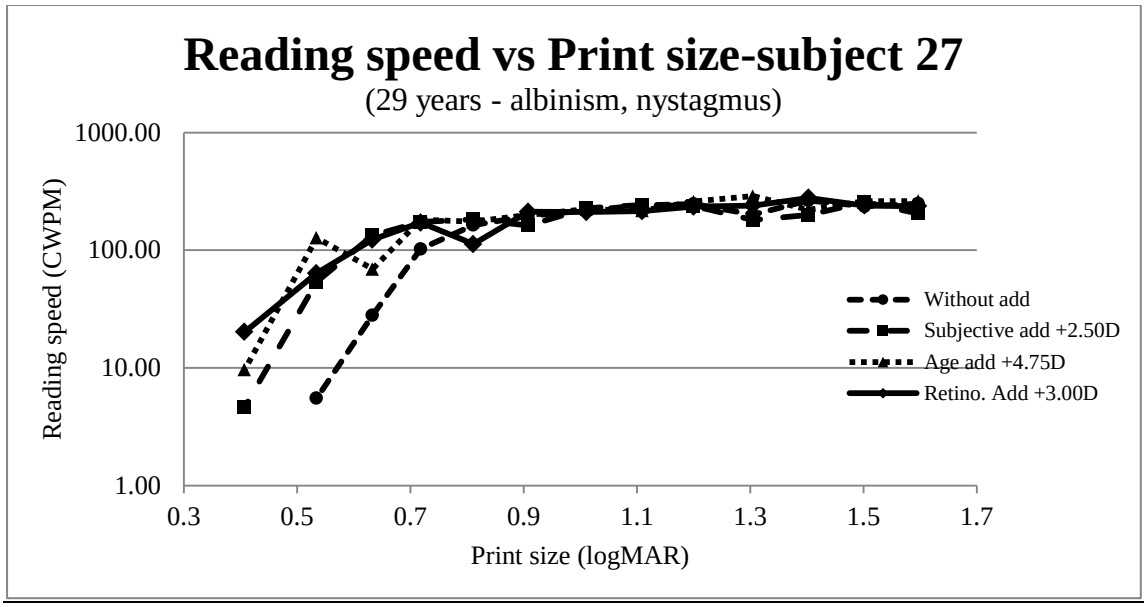

Figure 5:15 Reading speed against print size for participant 27.

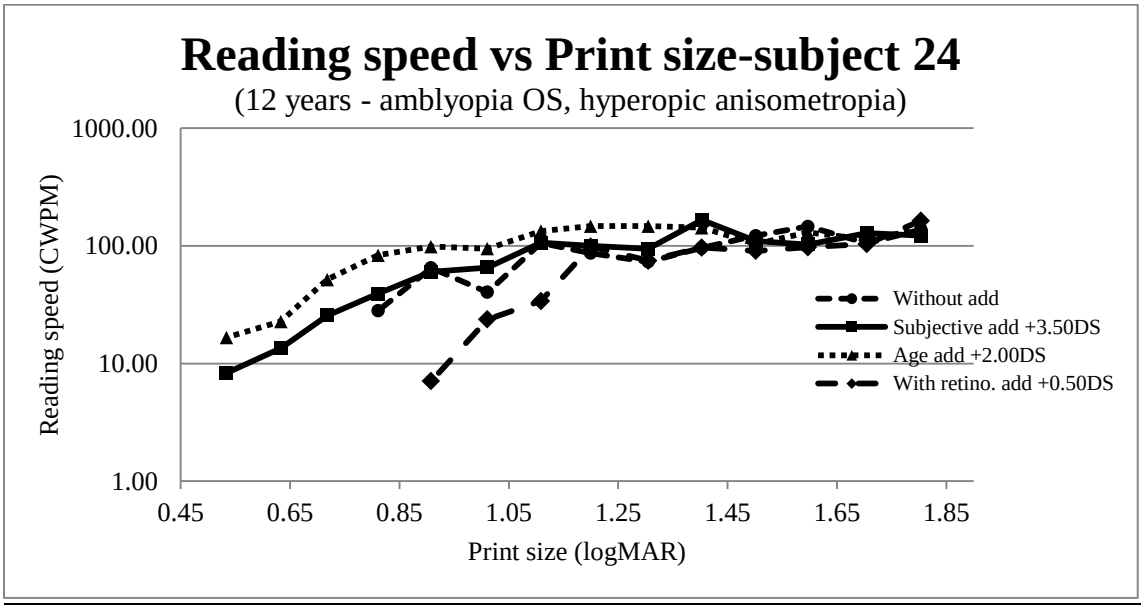

Figure 5:16 Reading speed against print size for participant 24.

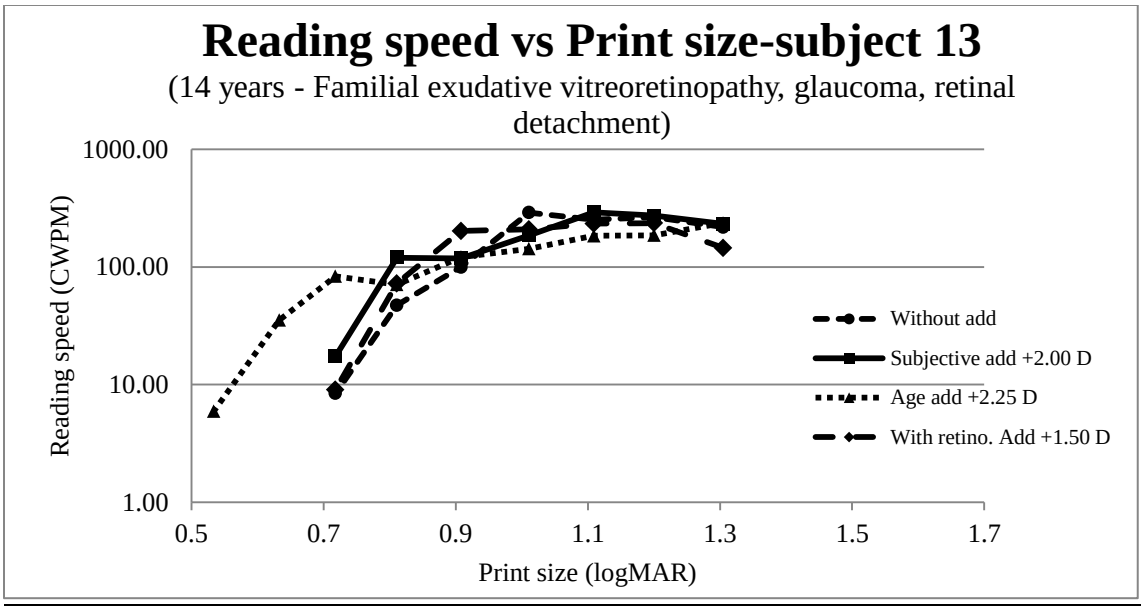

Figure 5:17 Reading speed against print size for participant 13.

Some participants did not show any obvious improvement with any of the reading additions. Below are some examples (Figures 5:18-5:20). In the first example (Figure 5:18), reading performance measured by maximum reading speed, critical print size, the logarithm of the area under the reading speed curve and MNREAD threshold was not improved by any of the three reading additions. For the second and third example (Figures 5:19 and 5:20), reading performance was better without an addition compared with all three reading additions. Figures of reading speed against print size for all the participants are given in Appendix B.

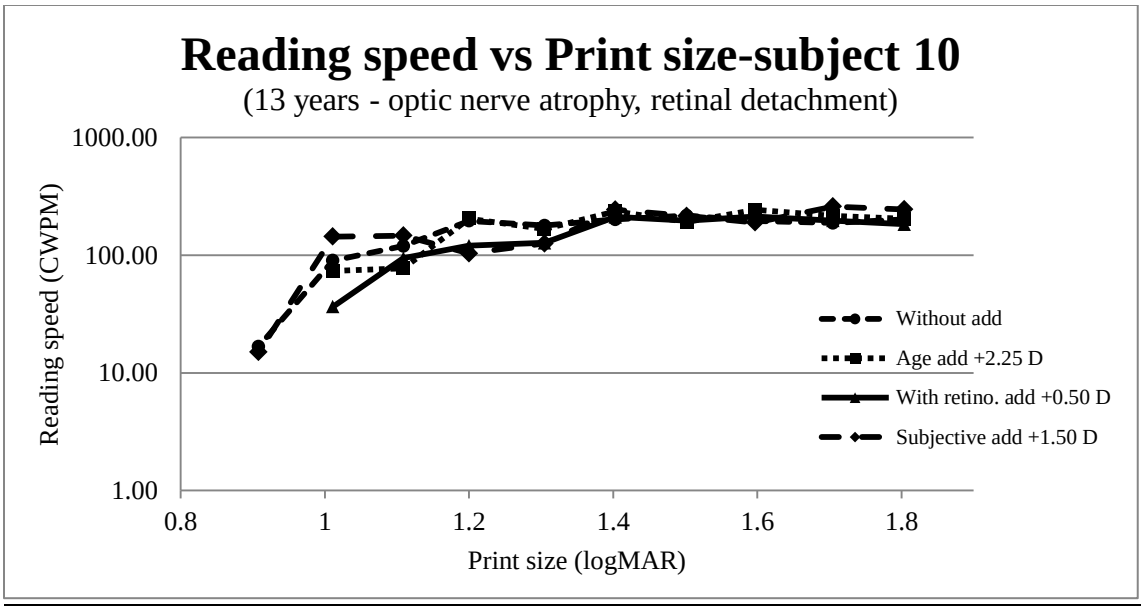

Figure 5:18 Reading speed against print size for participant 10.

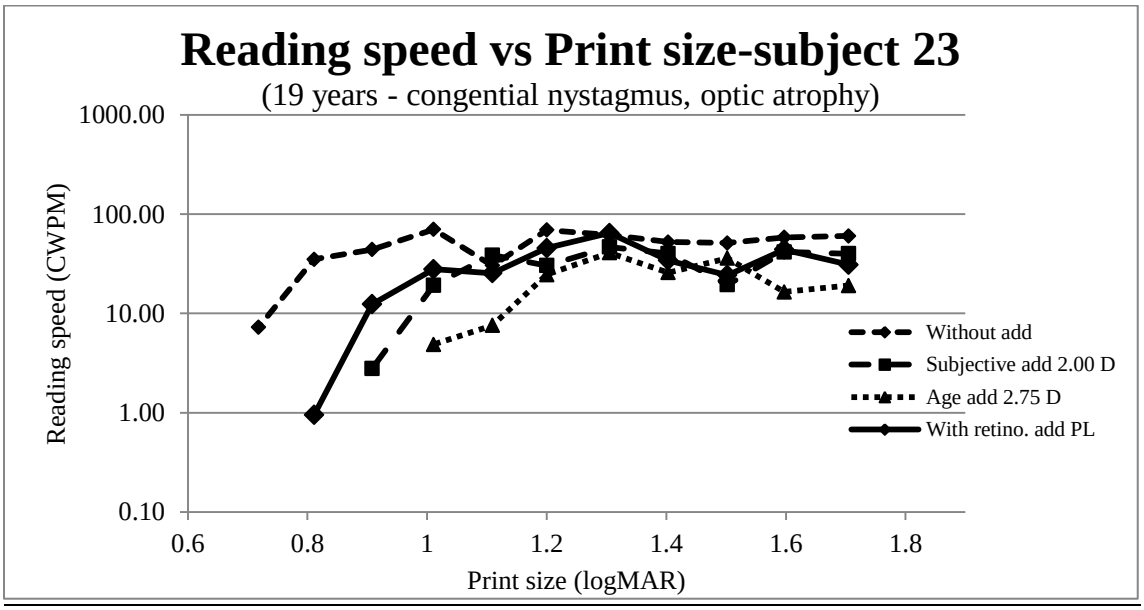

Figure 5:19 Reading speed against print size for participant 23.

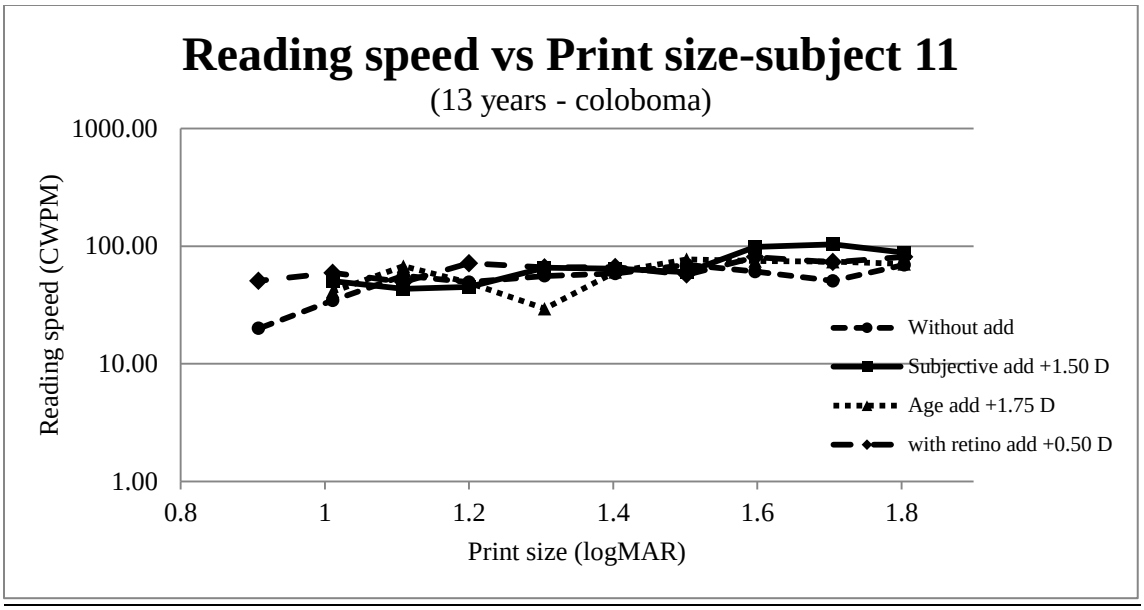

Figure 5:20 Reading speed against print size for participant 11.

5.4 Prediction of reading performance

The subjectively determined reading addition and age based reading addition gave rise to an improvement in the logarithm of the area under the reading speed curve and MNREAD threshold for the participants with reduced accommodation. Univariate analysis and forward step-wise linear regression analysis were conducted to determine if the improvement in reading performance could be predicted by various factors measured in the study. Similarly, univariate and multiple regression were applied to study if these factors might predict habitual reading performance without any reading addition, as measured by maximum reading speed, critical print size (CPS), the logarithm of the area under the reading speed curve and the MNREAD threshold. The independent variables used in the univariate analysis were distance visual acuity, near visual acuity, contrast sensitivity, lag of accommodation and age. The time spent on reading each day,

perceived difficulty of reading regular print and whether or not the participant received training for the usage of his/her low vision aids were not included in the multivariate analysis as not all participants had taken part in the questionnaire, and therefore those participants would get excluded from the whole analysis.

Lastly, a univariate followed by a multivariant analysis was undertaken to determine which visual factors might predict measures from the questionnaire i.e. difficulty with reading, time spent reading and training.

5.5 Prediction of improvement with reading additions

Both univariate and multivariate analysis showed that the improvement in reading performance with either the subjective addition or the age addition as measured by the maximum reading speed, the critical print size, the logarithm of the area under the reading speed curve or the MNREAD threshold was not predicted by any of the visual factors that were measured in this study ($p>0.05$).

Analysis of individual data showed that there were some participants (12/30) who showed a clear improvement in reading performance with at least two reading additions (one participant was considered to have a clear improvement with an addition as she showed a very definite improvement with this addition). All but one of the participants in this group had reduced accommodation for their age, but there were no other significant differences e.g. visual acuity, age, contrast sensitivity and area under the reading speed curve between those who showed a clear improvement and those who did not (t-test, $p>0.05$). Among the group who did not gain an obvious improvement (18/30), there were some with normal and some with abnormal

accommodation, i.e., some participants who did not show an improvement in reading performance had abnormal accommodation.

5.6 Prediction of habitual reading performance

Habitual reading performance without an addition was correlated with some measured factors.

Near visual acuity as measured with the Bailey-Lovie text chart was associated with the critical print size ($r=0.77$, $p<0.0005$, Figure 5:21-A), maximum reading speed ($r=-0.443$, $p=0.021$, Figure 5:21-B), contrast sensitivity ($r=-0.409$, $p=0.034$, Figure 5:21-C) and distance visual acuity (r=0715, $p<0.0005$, Figure 5:21-D).

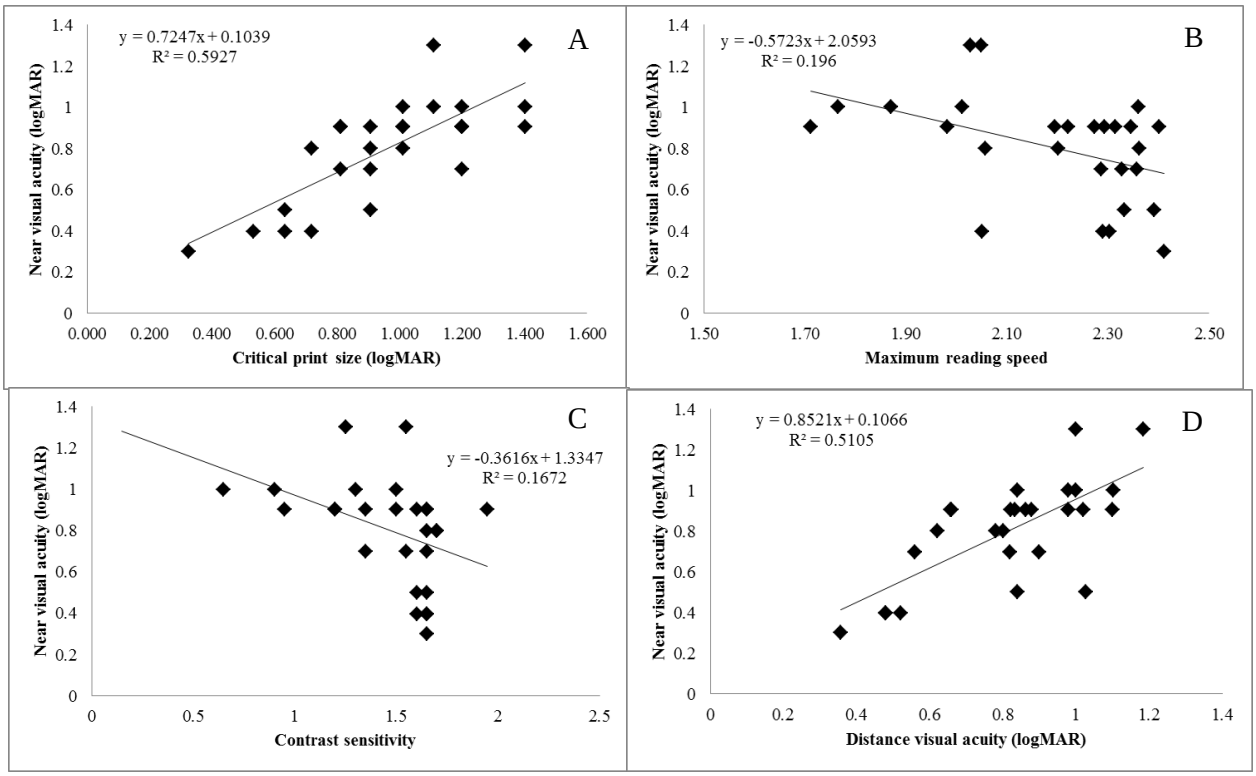

Figure 5:21 Scattergrams showing the correlations between near visual acuity and A. critical print size, B. maximum reading speed, C. contrast sensitivity and D. distance visual acuity.

MNREAD threshold without an addition was associated with the contrast sensitivity (r=-0.431, p=0.017, Figure 5:22-A) and distance visual acuity (r=0.728, p<0.0005, Figure 5:22-B).

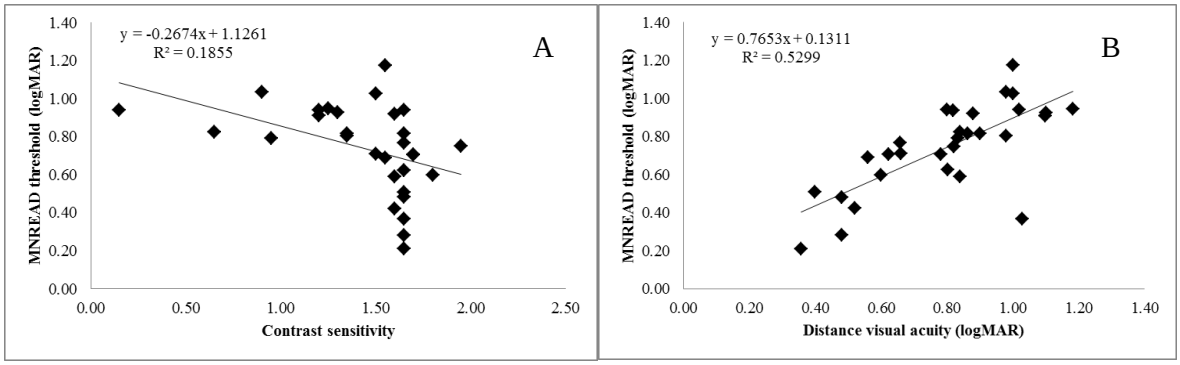

Figure 5:22 Scattergrams showing the correlations between MNREAD threshold and A. contrast sensitivity and B. distance visual acuity.

The critical print size was associated with MNREAD threshold (r=0.904. p<0.0005, Figure 5:23-A), distance visual acuity (r=0.681, p<0.0005, Figure 5:23-B) and contrast sensitivity (r=-0.428, p=0.018, Figure 5:23-C).

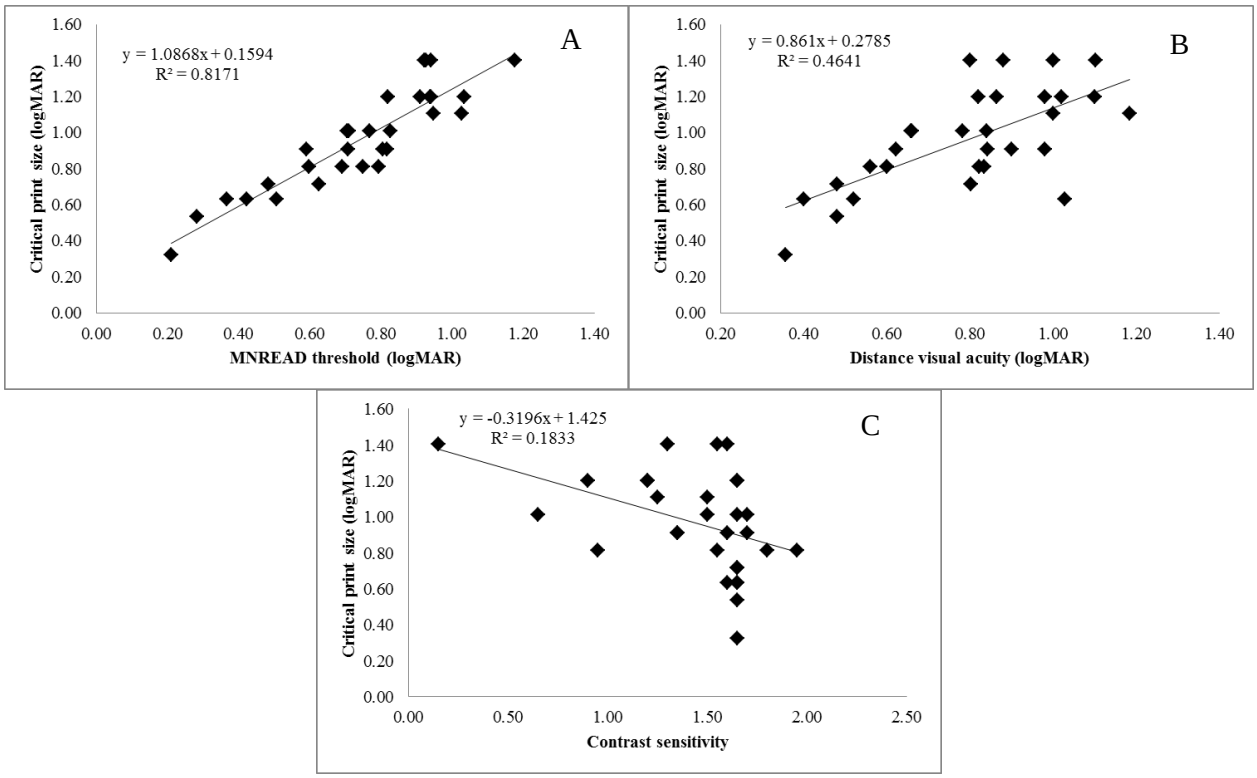

Figure 5:23 Scattergrams showing the correlations between critical print size and A. MNREAD threshold, B. distance visual acuity and C. contrast sensitivity.

The logarithm of the area under the reading speed curve was associated with the maximum reading speed (r=0.361, p=0.05, Figure 5:24). These did not remain significant after adjusted Bonferroni correction.

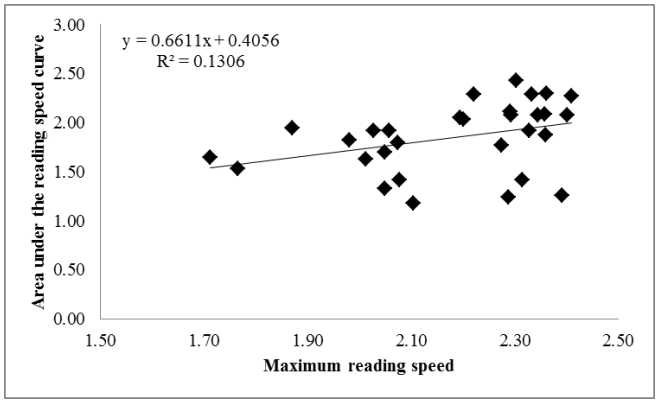

Figure 5:24 Scattergram showing the correlation between area under the reading speed curve and maximum reading speed.

Optimum acuity reserve was associated with maximum reading speed (r=0.437, p=0.016, Figure 5:25-A), critical print size (r=0.572, p=0.001, Figure 5:25-B) and age of the participants (r=0.449, p=0.013, Figure 5:25-C).

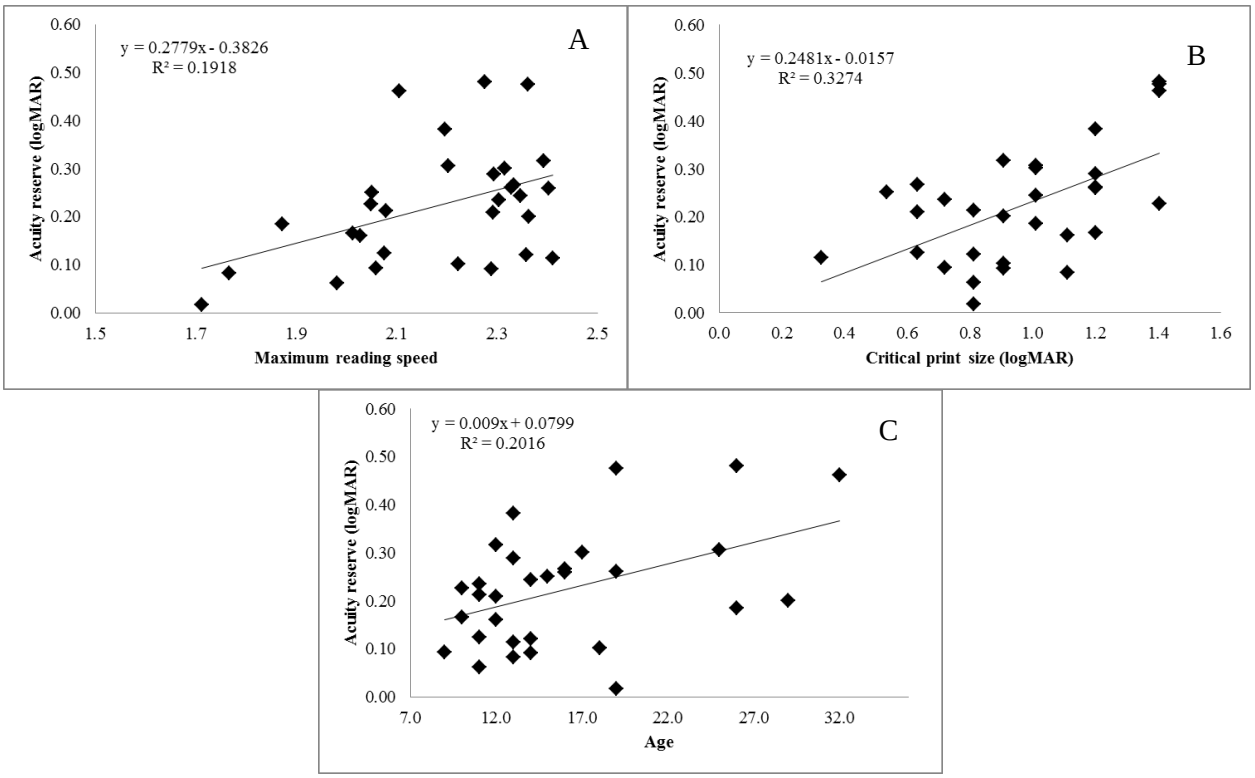

Figure 5:25 Scattergram showing the correlation between optimum acuity reserve and A. maximum reading speed, B. critical print size and C. age of the participants.

For difficulty of reading and time spent on reading each day (which had just four categorical levels) a Spearman correlation was conducted to study if difficulty of reading and time spent on reading each day correlated with any of the visual factors. Difficulty of reading correlated with near visual acuity (Spearman correlation coefficient=0.620, p=0.0009), MNREAD threshold (Spearman correlation coefficient=0.450, p=0.02) and maximum reading

speed (Spearman correlation coefficient=-0.472, p=0.014). Time spent on reading each day correlated with the area under the reading speed curve (Spearman correlation coefficient=0.659, p=0.0024).

All of these models for predicting reading performance remain significant after applying the adjusted Bonferroni correction (Jaccard & Wan 1996). This method helps to control the probability of making type 1 error, rejecting the null hypothesis when it is true.

A forward step-wise linear regression analysis was conducted to determine if the habitual reading performance (CPS, maximum reading speed, MNREAD threshold, and area under the curve) could be predicted by distance visual acuity, contrast sensitivity, lag of accommodation or age. The other variables from the reading speed against print size plots were not included as independent variables, since they are derived from the same data. For near visual acuity and subjective addition, variables that were derived from the reading speed against print size were also included. Models that were significant after applying the adjusted Bonferroni correction across all the models are shown in Table 5:2.

Table 5:2 Multiple regression results of habitual reading performance predicted by measured visual factors.

Dependent variable	R^2 at each step	Co-efficient	t	p
Near visual acuity				
Critical print size	0.593	0.967	9.319	<0.0005
Acuity reserve	0.784	-0.109	-4.599	<0.0005
MNREAD threshold without addition				
Distance visual acuity	0.530	0.765	5.622	<0.0005
Critical print size without addition				
Distance visual acuity	0.464	0.839	5.196	<0.0005
Age	0.560	0.014	2.433	0.022
Subjective addition				
Age	0.340	0.118	3.685	0.001
Near visual acuity	0.462	1.565	2.332	0.028

6: Discussion

To the author's knowledge, this is the first study which compares different methods of determining reading additions in children and young adults with low vision and their possible effect on reading performance. It is also one of the few studies of reading performance in children with low vision.

6.1 Habitual reading performance and low vision devices of the sample

Optimum acuity reserve was calculated as the difference between the critical print size and MNREAD threshold on a logarithmic scale, which is equivalent to the ratio if the units are linear. In the current study the optimum acuity reserve ranged between 1x to 3x and the mean was found to be 1.7x. Most of the participants (11/30) had an acuity reserve of 1.6x. These results are lower than found in other studies. Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) reported that an acuity reserve of 2.5x to 7x was needed for children to achieve optimum reading rate. In a more recent study, Lueck et al. (Lueck et al. 2003) showed that children with low vision needed at least three times acuity reserve to achieve maximum reading rate. Kartha (Kartha 2010) reported that an acuity reserve of 2.6x is needed for children with low vision to read with maximum reading rate. The differences may be attributed to the different distances that were used to measure the acuity reserve. Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) calculated acuity reserve as the difference between logarithm of the near visual acuity and logarithm of the critical print size at 10cm. Kartha (Kartha 2010) used the participant's habitual

reading distance and the acuity reserve was the ratio between print size threshold to the critical print size. Lueck et al. (Lueck et al. 2003) defined acuity reserve as the ratio between critical print size and near visual acuity but used different viewing distances (40, 7 and 5 cm) across their participants. In the current study a fixed working distance of 12.5cm was used to measure the reading performance from which the acuity reserve was determined. However, it is still not clear why there was such a difference between the present results and those of Lovie-Kitchin et al, since a similar working distance was used.

Different sample sizes and age groups between the studies may have an influence on the average of the optimum acuity reserve. Lueck et al. (Lueck et al. 2003) included six participants of similar age, all in their fourth grade. Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) studied 71 students between the age of 7 to 18 years. Kartha (Kartha 2010) had 42 students with low vision between the age of 8 to 20 years. The current study had a lower sample size (30 participants) and a wider age range which may affect the required acuity reserve. The acuity reserve also may be affected by the acuity in the sample, as Lovie-Kitchin (Lovie-Kitchin et al. 2001) found that those with poorer acuity required less acuity reserve than those with better acuity.

The current study showed that most participants used a CCTV (14/26) in the school setting and/or at home. This might be because schools are equipped with electronic devices that help low vision children in reading. Hand-held magnifiers were used by seven participants (7/26). A hand-held magnifier is portable and can be afforded by most people. Fewer participants (6/30) had a spectacle magnifier and/or a reading addition and this might highlight the fact that more low vision patients should be examined for reading additions as a reading addition might improve their reading performance. This pattern of low vision devices usage is different from

other studies in the literature. Kartha (Kartha 2010) reported that among the 42 participants in her study, the most frequently used near low vision aid was a bifocal spectacle (16 participants) followed by using a close working distance to gain relative distance magnification (14 participants). Although Kartha separated these two categories, they are optically similar, as both provide relative distance magnification. Seven participants used large print books and two participants used a combination of bifocals and another near low vision aid. Only three participants used one of the following low vision aids: bar magnifier, stand magnifier or portable CCTV. Kalloniatis and Johnston (Kalloniatis & Johnston 1990) found that the most used near visual aids were stand magnifiers followed by hand-held magnifiers, then CCTVs. They suggested that for near viewing, children preferred to modify their working distance rather than using a low-powered aid. McCurry et al. (McCurry et al. 2005) conducted a study to investigate the effectiveness of magnifiers to help children access materials of regular sized print. Their results (McCurry et al. 2005) agree with those of Kalloniatis and Johnston (Kalloniatis & Johnston 1990) in that the most common magnifiers prescribed in their study were stand magnifiers. Leat and Karadsheh (Leat & Karadsheh 1991) also found that the first choice of near low vision aids for children was a stand magnifier followed by a hand held magnifier. Only14.6% used reading spectacles or bifocals. Thus, there are some differences between these studies in the literature, although the modal result seems to be that stand magnifiers are often preferred by children. However, it must be remembered that these studies took place over a 20 year period and in different countries. The differences may simply reflect differences in prescribing preferences, costs, financial support or which professionals are involved in providing devices. These differences between studies in the low vision devices that were used and/or prescribed for children might mean that more studies should identify which are the best devices

to be used by children. Most studies have simply reported what children are currently using, rather than systematically comparing which devices function best for children.

Maximum reading speed without an addition ranged between 53 wpm to 269 wpm (mean 156 ± 64 wpm). All but one of the participants had a reading speed of more than 80 wpm which is considered adequate for fluent reading (Whittaker & Lovie-Kitchin 1993). Only one participant had a reading speed of less than 80 wpm. This participant obtained 52 wpm which is more than 40 wpm which classified as spot reading and is considered to be adequate for activities of daily living (Whittaker & Lovie-Kitchin 1993). Mangold and Mangold (Mangold & Mangold 1989) reported that 60 wpm is needed for grade 3 level. This participant had 0.95 contrast sensitivity which was one of the lowest CS measurements in the group and may account for his slow reading rate compared to the rest of the group. In fact, this participant may need other methods for accessing text, such as Braille or audio. All other participants had a reading speed of more than 80 wpm which is considered adequate for grades 4 to 6 in children with low vision (Fellenius 1996). This range of reading speeds is similar but slightly higher than reported by Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) in their study on reading performance in children. They reported 28 wpm to 254 wpm as the range of maximum oral reading rate (146.5 ± 61.2 wpm).

Kartha (Kartha 2010) reported the duration of sustained reading of children with and without low vision. The data were collected as self-reported sustained reading outside school. Kartha's (Kartha 2010) results showed that there was a significant difference between children with and without low vision. Children with low vision read for a shorter period of time than those with normal vision. Children without low vision read for 30 minutes to two hours whereas children with low vision read between 20 minutes to one hour. Their values are lower than those

in the current study, in which data of the time spent reading each day were collected from a short questionnaire. Most children with low vision reported that they either read between five minutes to two hours (9/26) or two hours to four hours (9/26) per day. Participants were asked about the total time they spent reading each day which includes school work, internet surfing and even cell-phone texting. The difference in the results between the current study and Kartha's (Kartha 2010) study is accounted for by the way the data were collected. Kartha asked about the time spent on sustained reading outside school only whereas in the current study the total time spent reading each day was reported.

Smith and Erin (Smith & Erin 2002) conducted a study to investigate if practice/training of reading glasses or optical devices had an effect on reading efficiency. Three children participated in the study. They read large print only and had never experienced reading regular print with reading glasses and/or optical devices. The results of the study showed that all participants had higher oral and silent reading rates after daily practice sessions. Smith and Erin suggested that training sessions may have a positive effect on reading efficiency with glasses/optical devices. In a study by Cox et al. (Cox et al. 2009) the effectiveness of training on the use of low vision aids was investigated. A stand magnifier (Eschenbach, 23 D, 6x) was used in the study. Children aged between 37 to 77 months of age participated. The children were asked to do a task that was developed by Cox et al. in which children had to follow a set of optotype (picture) trails. If the task was performed correctly, following the start picture would lead through a set of pictures to a "hidden finish picture". According to Cox et al, this task enabled the measurement of "dynamic real-life" use of magnifiers. Children were divided into two groups. The first group was trained with the magnifier and the second group was trained without a magnifier. Comparison between the two groups in performing the task showed that

training increased the children's ability to perform the task quantitatively and qualitatively. The study also showed that the children who were trained with a magnifier were 4.3 times better in finding the correct finish picture whereas children who were trained without a magnifier became 2.5 times better at finding the finish picture. It was also suggested that the prescription of a low vision device for children > 42 months may be beneficial if the proper training is provided. Both these studies suggested that training on the use of a low vision aid improves a child's capabilities in using that aid.

In the present study, the prevalence of participants who stated that they had a training session on the use of their low vision devices was determined by the questionnaire. The results showed that 57% had a training session on the usage of their low vision device/s. T-tests between participants who had training sessions and participants who did not receive any training on their low vision device/s showed that there was a significant difference in maximum reading speed and MNREAD threshold. Participants who had training sessions had lower reading rate and higher (worse) MNREAD threshold than participants who had not receive any training on their low vision device/s. This is, perhaps, the opposite from what is expected and is initially not in agreement with the studies mentioned above. However, it is possible that those participants with worse acuity and lower reading speeds were identified as needing training. They would be more likely to have stronger powered devices and therefore be seen as needing training more compared to those with better acuity. This may highlight the lack of training sessions in children and young adults with low vision. Prescribed low vision devices should provide the optimum magnification that would lead to better reading performance. Professional training sessions could further improve the person's capabilities on the usage of a low vision device. As a result, the optimum reading performance could be achieved.

6.2 Impact of a reading addition for the whole group

The first hypothesis for this study was that there would be a difference in the dioptric power obtained by the three methods used to determine a reading addition. The first hypothesis was found to be true for the group as a whole. The reading addition power that was determined by the dynamic retinoscopy technique was significantly lower than the age addition. The age addition might under- or overestimate the required addition for some participants at 12.5cm as it does not take into account the actual accommodation response for each individual. Thus, the age calculation method gives all individuals of the same age the same dioptric power. On the other hand, the reading addition that was determined by dynamic retinoscopy allowed for the individual's ability to accommodate for a target at 12.5cm. The dioptric power of the reading addition that was determined by the dynamic retinoscopy technique was lower on average than the age addition because some of the participants had normal accommodation at this 8D demand and in these cases the retinoscopy addition power was zero. The subjective addition dioptric power was close to the age dioptric power, with an average value of 2.25 D compared to 2.46 D. However, the subjective addition had wider range (0.50 D to 7 D) than the age addition (1.50 D to 1.75 D).

Presumably, the subjective addition also is influenced by the participant's accommodation, as is the retinoscopy addition. However, while determining the retinoscopy addition, if the participant's accommodation was seen to be within the normal range, no addition would be added. But with the technique for determining the subjective addition, an addition was always offered. Even in cases where the accommodative response may have been adequate, when an addition was offered subjectively, some stress may have been taken off the accommodation system, the accommodation may have relaxed and the addition was preferred

and accepted. This would lead to an addition being accepted subjectively, although determined unnecessary by retinoscopy, and would lead to the higher average subjective addition compared to the retinoscopy addition.

Reading performance measured by maximum reading speed, critical print size, MNREAD threshold and area under the reading speed curve did not show any difference between the three reading additions and without a reading addition. This may be accounted for by the participants who had normal accommodation (12/30). Those participants might not need a reading addition of any kind and would have gained no benefit from it, particularly for short term reading, as was the task in this study.

Another analysis was conducted on the younger group of the participants (20/30). ANOVA results for the younger group was similar to the whole group results. There was a significant difference between the reading additions powers. The power of the age addition and the subjective addition were significantly higher than the addition that was determined by dynamic retinoscopy. As for the whole group, this may be accounted for by the participants who had normal accommodation (8/20) at the 8D demand, as their reading addition for the dynamic retinoscopy technique was recorded as zero. The results of the ANOVA of measurements of reading performance, including maximum reading speed, critical print size, MNREAD threshold and area under the reading speed curve, did not show any difference between the three reading additions and without a reading addition for the younger group of the participants. This might be accounted for the small sample size and also the high percentage of participants who had normal accommodation in that group.

6.3 Impact of a reading addition for the sub-group with abnormal accommodation

Sixty percent of the sample had abnormal accommodation, which was lower than anticipated and is a lower percentage than reported by Leat and Mohr (Leat & Mohr 2007). This may be accounted for by the different sample sizes between the studies and for how reduced accommodation was determined. In the present study, reduced accommodation was defined as an accommodation response that did not match the normal age limits at 12.5cm. In the Leat and Mohr study, accommodation responses were measured at four different accommodative demands and the mean error of accommodative response was calculated. The slope of the accommodative response regression line fitted against the accommodative demand was also calculated. A reduced accommodative response was considered if mean accommodative error and/or the slope did not match the normal limits according to age.

Once those with normal accommodation were removed, there was no significant difference in dioptric power obtained by the three methods used to determine the reading additions, although all the reading addition powers were significantly greater than zero. Correlation coefficients were used to determine how much agreement there is between the different methods for individual participants. There was a significant correlation between the subjective addition power and the dynamic retinoscopy addition power ($r=0.418$, $p=0.042$) and a significant correlation between the dynamic retinoscopy addition and the age addition ($r=0.629$, $p=0.002$), but there was no significant correlation between the subjective addition and the age addition ($r=0.099$, $p=0.347$). These correlations indicate that there is an association between the dioptric powers obtained by the three methods. However, because the correlation is not high (particularly between the subjective and age addition), they are not clinically completely interchangeable.

ANOVA results showed that the logarithm of the area under the reading speed curve was higher with the subjective addition compared to no reading addition. The logarithm of the area under the reading speed is a measure of the total reading performance across a range of print sizes. On average, children and young adults with low vision who had reduced accommodation benefited from a reading addition and had a better overall reading performance compared to no addition. Clinically, a reading addition determined subjectively might be one of the best methods to use when the patient's response is reliable.

The MNREAD threshold was better with the age addition compared to no addition. On average, participants read smaller print with an addition based on their age than without an addition. This helps to answer the question that was posed by Leat and Mohr (Leat & Mohr 2007). Many persons with low vision have reduced accommodative response (Leat & Mohr 2007, Ong et al. 1993, White & Wick 1995, Leat et al. 1999) and it would be expected that correcting the large accommodative lag would improve their visual acuity. However, decreased visual acuity in patients with low vision decreases their sensitivity to blur and causes an increase in their depth-of-focus (Wang & Ciuffreda 2006, Legge et al. 1987). This increased depth of focus may be the cause of the reduced accommodative response (Leat & Mohr 2007). Their increased depth-of-focus may also help them to tolerate their decreased accommodation (Legge et al. 1987). Hence they may attain optimum resolution of close objects as long as their accommodative response (lead or lag of accommodation) does not exceed their depth-of-focus. In other words, the accommodation system may be placing an image on the retina which is at the limit of the resolution of the system, and further improved focus might not improve acuity i.e., they may not benefit from a reading addition (Leat & Mohr 2007). The results of the present study showed that some individuals with reduced accommodation response were sensitive to blur

and did benefit from a reading addition at 12.5cm. The MNREAD threshold was improved with reading addition (subjective addition) compared with no addition. This indicates that children and young adults with low vision do benefit from a reading addition, despite their increased depth of focus.

6.4 Prediction of improvement in reading performance

According to both univariate and multivariate regression, improvement in reading performance was not predicted by any of the factors that were measured in the study. Some insight was gained into those who would gain improvement in reading performance by grouping the participants into those who showed an obvious improvement with at least two reading additions (expect one participant who showed a large improvement with one addition) and those who did not show an improvement with the reading additions (improvement with one reading addition only). All but one participant who showed a significant improvement based on this grouping were participants with abnormal accommodation for their age at 12.5cm. Thus poor accommodation was the only factor that we were able to identify which indicates which patients are likely to benefit from a reading addition.

6.5 Prediction of habitual reading performance

In the present study, the habitual reading performance could be predicted by certain factors. Studies in adults have found that reading rate is correlated with contrast sensitivity (Rubin & Legge 1989), but this association is less often found in children. Kartha (Kartha 2010)

did not find any correlation between maximum reading rate and contrast sensitivity. In the present study there was no significant association between maximum reading rate and contrast sensitivity.

Near visual acuity was associated with the critical print size ($R=0.967$, $p<0.0005$) and the acuity reserve ($R=-0.109$, $p<0.0005$). As the near visual acuity became higher (worse) the critical print size also became larger (worse) and the acuity reserve was lower. This is similar to what Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) found for her group of children with low vision ($R=-0.58$, $p=0.001$). Lovie-Kitchin et al. suggested that children, unlike adults, are trained to make the maximum of their poor near acuity with a low acuity reserve.

The MNREAD threshold could be predicted by the distance visual acuity. The critical print size could be predicted by the distance visual acuity and the age of the participant. It is not unexpected that these acuity measures would be significantly correlated with each other. The power of the subjective addition could be predicted by the age ($R=0.118$, $p=0.001$) and the near visual acuity of the participant ($R=1.565$, $p=0.028$). As the person gets older, s/he is more likely to accept a higher plus lens, because s/he will have lower accommodation. Also, with poorer near visual acuity a higher subjective addition power is preferred. Again, this might be linked to lower accommodation response in people with poorer acuity.

The study of Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) is, to the author's knowledge, the only published comprehensive study on reading performance in children with low vision. Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) found that maximum reading rate in children aged 8-18 years correlated with age ($R=0.47$, $p<0.001$). To compare the results of the present study to those of Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001), the data of the children

between 8 and 18 years were analyzed separately to determine predictive factors of reading performance. There was a significant correlation between maximum reading speed and age ($R=0.445$, $p=0.049$). As the children became older, their reading speed increased and this may be because they were in the process of learning how to read and their general reading skills were improving. Legge et al. (Legge et al. 1992) found an opposite correlation between reading speed and age in elderly people with low vision. Elderly people with low vision seem to have slower reading speeds than younger adults with low vision. In the present study for the younger group, maximum reading rate also correlated with near visual acuity as measured by the Bailey-Lovie text chart ($R=-0.505$, $p=0.022$), i.e., as acuity improved (became more negative on the logMAR scale), reading speed improved. This is similar to the results of Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) in which they found that maximum reading rate correlated negatively with near visual acuity ($R=-0.62$, $p<0.001$). It is also similar to the results reported by Kartha (Kartha 2010), where there was again a significant correlation between near visual acuity and maximum reading rate ($R=-0.442$, $p=0.003$) and to the results of Kalloniatis and Johnston (Kalloniatis & Johnston 1990) who also found a correlation between "habitual near visual acuity" and reading rate ($R=-0.58$, $p<0.001$). Distance and near visual acuity were highly correlated in the current study ($R=0.728$, $p=0.0002$) and in the Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) study ($R=0.84$, $p<0.001$). In fact many of the "acuity type" measures were intercorrelated e.g. critical print size, distance and near acuity, acuity reserve.

This was one of the few studies that has measured reading performance and questioned young participants about their perceived difficulty with reading. As was expected, there was a negative correlation between the perceived level of difficulty reading regular print size and maximum reading speed (Spearman correlation coefficient=-0.472, $p=0.014$). Participants who

experienced difficulty reading regular print size read at a slow rate. There was also an association between the perceived level of difficulty reading regular print size and MNREAD threshold (Spearman correlation coefficient=0.450, p=0.02) and measured near visual acuity (Spearman correlation coefficient=0.620, p=0.0009). People with low vision who had greater difficulty reading regular print size have poorer near visual acuity.

The time spent on reading each day was associated with the area under the reading speed curve (Spearman correlation coefficient=0.659, p=0.0024). People who had better reading performance (on average) were more likely to report spending more time on reading each day. Kartha (Kartha 2010) showed a similar finding in her study. She found that there is a significant correlation between the duration of sustained reading and maximum reading speed (R=0.447, p=0.001).

6.6 Clinical applications

There was an improvement in the area under the curve and MNREAD threshold with the age addition and the subjective addition, respectively. There were also clear improvements in reading performance with a reading addition in some individual data. These findings indicate that an assessment of a reading add should be considered for inclusion in a low vision assessment leading of children and young adults with low vision.

In the present study, linear regression did not show any of the factors that were measured in this study to be predictors of an improvement in reading performance. Analysis of individual data showed that some participants had a clear improvement in reading performance with at least two reading additions (plus one participant who had a definite improvement with one addition).

All but one of these participants who had clear improvement in reading performance had reduced accommodation. However, not all of those with abnormal accommodation gained an improvement with an addition. Hence, clinically an eye care practitioner should demonstrate a reading addition in a low vision assessment, particularly when accommodation is reduced, as it might help in improving reading performance in children and young adults with low vision. However, not all those with reduced accommodation will benefit. Since the power of the subjective add was associated with age and visual acuity, it is also important to demonstrate such an addition to those with poorer vision and to demonstrate adds again as the person ages i.e. although an add may not be accepted when younger, it may be accepted later in life.

Since both the age addition and the subjective addition resulted in some measurable improvement in reading, it is suggested that the age calculation method could be used to determine the tentative addition power and this then be refined by the subjective method. This may be more efficient than increasing the add power a dioptre at a time, as in the present study. The tentative reading addition based on the patient's age could be determined prior to the patient's visit. This would shorten the examination time. Hanlon et al. (Hanlon et al. 1987) reported that determining the tentative reading addition in presbyopic patients based on the patient's age resulted in less errors than other methods. The age add determines the starting point based on the minimum amplitude of accommodation according to the participant's age and working distance and the final (prescribed) reading addition power would be refined based on the participant's subjective response. The dynamic retinoscopy technique could be used with young patients or where the patient's response in unreliable.

6.7 Limitations of the study

Some measurements of reading performance did not show any improvement with any of the reading additions. This is might be because of the use of a fixed working distance (12.5cm) for reading tasks which was not always the same as the participant's habitual reading distance. The majority of participants habitually read at a distance further than 12.5cm. Lovie-Kitchin et al. (Lovie-Kitchin et al. 2001) used a fixed distance of 10cm. Lovie-Kitchin suggested that the correlation between near visual acuity and reading rate in children with low vision might be stronger if the habitual distance were used in the study. Kartha (Kartha 2010) and Kalloniatis and Johnston (Kalloniatis & Johnston 1990) used the participant's habitual working distance in their measurements. However, Kartha (Kartha 2010) reported that the mean habitual viewing distances of children in her study was 11.67cm which is similar to the 12.5cms used in the present study. Similarly, another study in children and young adults with low vision showed that the most frequent habitual reading distance was 12.5cm (Leat, personal communication). Rosenfield et al. (Rosenfield et al. 2001) assessed working distances in children with normal vision between 6 and 11 years and reported that the most appropriate working distance for children is 25cm. They suggested using 25cm in all near-testing (i.e., visual acuity, oculomotor balance and dynamic retinoscopy) in children. However, the same distance might be not suitable in low vision patients due to reduced acuity and their use of relative distance magnification.

Two participants had monocular anisometropic amblyopia. They were asked to read with their amblyopic eye with their best eye occluded. These participants were not used to reading with their amblyopic eye. Also, they were not used to reading at this close reading distance (12.5cm) and therefore they may have performed differently than the rest of the group and this might have affected the results of the whole group on average. They may be more or less likely

to benefit from a reading addition: more likely, as they are not used to accommodating for the close working distance; less likely because they were able to accommodate successfully for the short duration of the reading task used in this study. The inclusion of these participants may have impacted the results of the whole group.

Originally, the sample size was calculation indicated that 37 participants were needed in the study. However, it was only possible to recruit thirty participants who met the study criteria within the timeline of the study. If the full sample had been recruited, it is possible that a significant difference in reading performance with one of the additions would have been found for the whole group.

6.8 Conclusion

This first hypothesis of the study was that there would be a difference in the dioptric power obtained by the three methods and this was found to be true. There was a significant difference in the dioptric powers determined by the three methods. The difference of the dioptric power was no longer significant in the sub-analysis of people with abnormal accommodation. Although the dioptric powers were significantly correlated between the different methods, the correlation coefficient was moderate, so they cannot be considered completely interchangeable. However, there are clinical situations where the subjective method is not possible, and then the clinician would have to rely on the age method, without subjective adjustment or the retinoscopy method.

The second hypothesis was that there would be an improvement in reading performance with at least with one of the reading additions compared to no addition and this was found to be

true in participants with abnormal accommodation. An improvement was found in the area under the curve with the subjective addition and in MNREAD threshold with the age addition.

Since improvement in reading performance could not be predicted by any of the factors that were measured in the study, a reading addition should be considered in a low vision assessment of children and young adults with low vision in patients with reduced accommodation. This means that either accommodation should be measured in a low vision assessment followed by a reading addition assessment if accommodation is reduced, or if accommodation is not measured, a reading add should be trialed in all young patients. It is important that the eye care practitioner should try a reading addition as this study found that reading performance was significantly improved in some young people with low vision. It is suggested the age method should be used to determine the tentative addition and refined with the subjective method for an optimum addition power.

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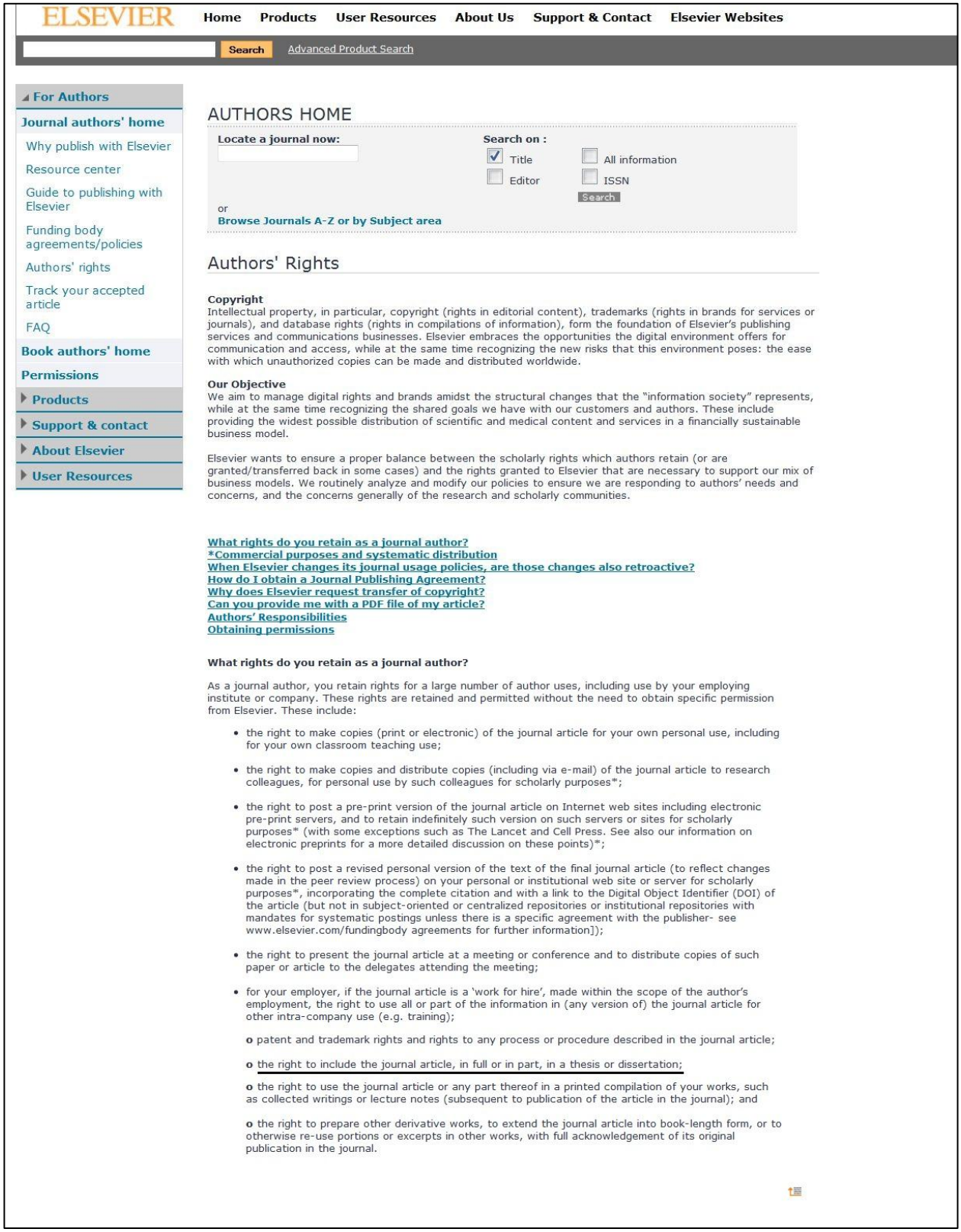

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Appendix A

Reading and low vision aids questionnaire.

Participant name _____

Current training/low vision aids questionnaire

1) Do you currently use any low vision aids for reading (spectacle magnifiers-stand magnifiers, CCTV, computer....)? If yes, please specify and say which you use for which type of reading.

Reading

- □ Spectacle magnifier
- □ Stand magnifier
- □ Hand-Held magnifier
- □ CCTV
- □ Other

2) Did you attend training sessions for the use of your low vision aids or for reading? If yes, for how many hours, please specify.

3) How long do you read each day?

- □ I don't read at all
- □ between five and 30 minutes
- □ between 30 minutes and 2 hours
- □ between 2 hours and 4 hours
- □ for more than four hours per day

4) What things do you read a bit everyday? (check all that apply)

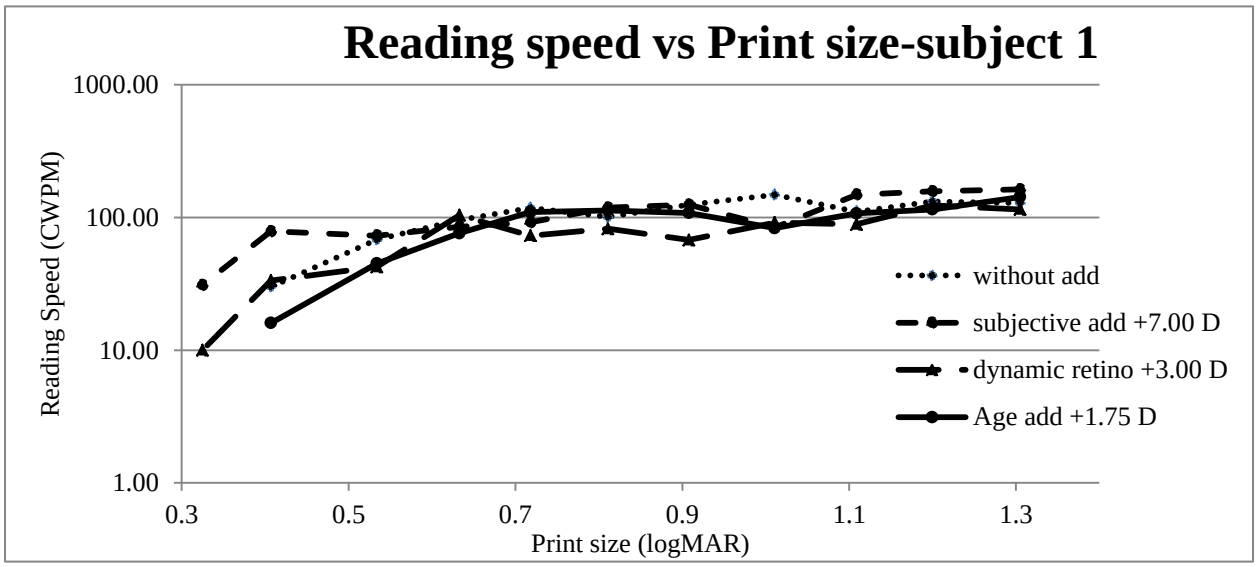
□ letters	□ Newspapers	□ other
□ magazines	□ bills	
□ books	□ recipes	
□ school work	□ package instructions	
□ computer	□ cell phone	

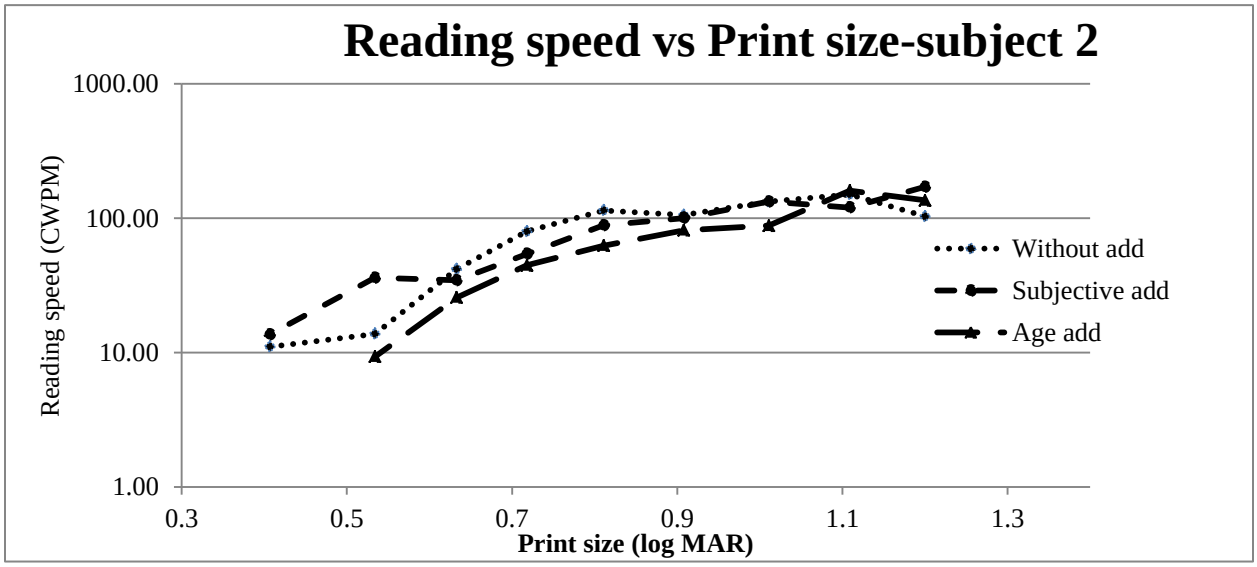
5) How much difficulty do you have reading regular print books?

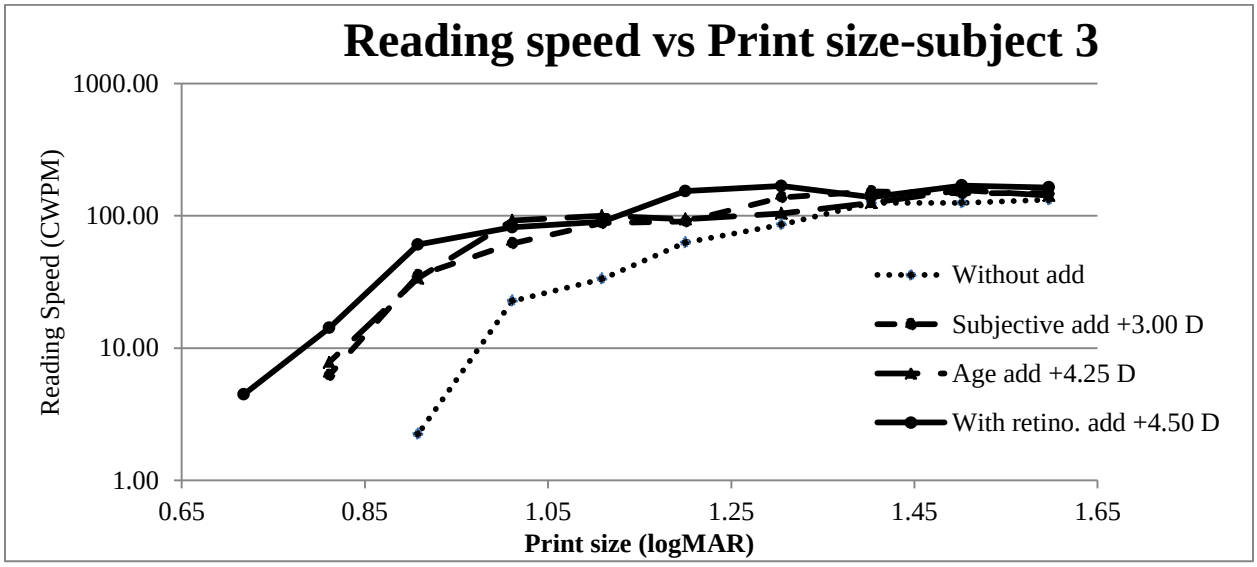
- □ No difficulty at all
- □ A little difficulty
- □ Moderate difficulty
- □ Extreme difficulty
- □ Can't do it at all.

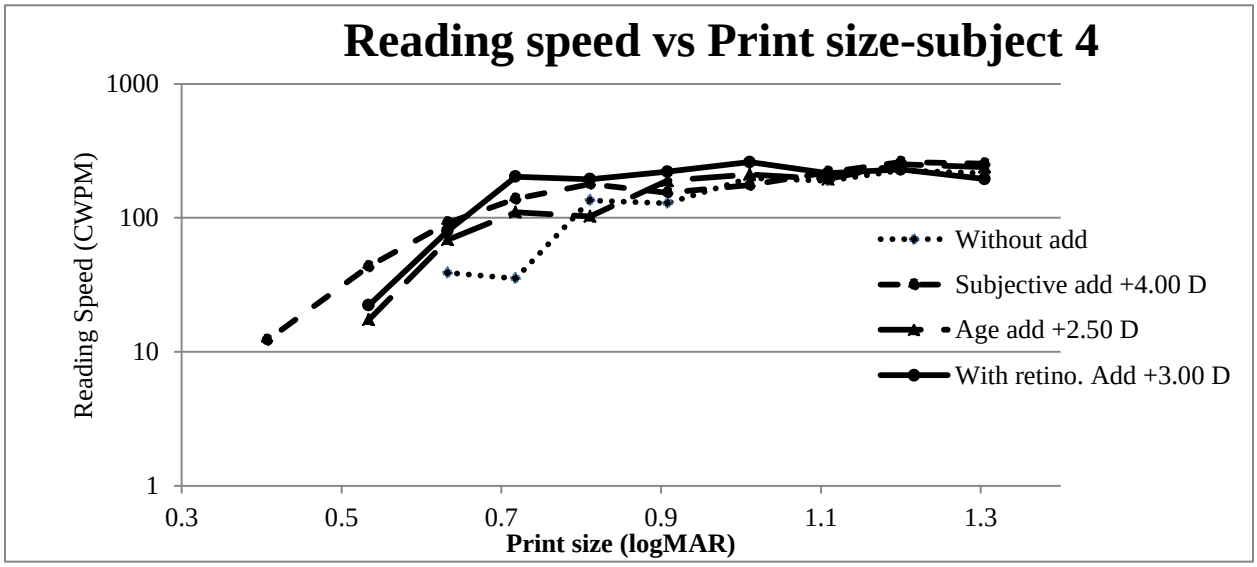
Appendix B

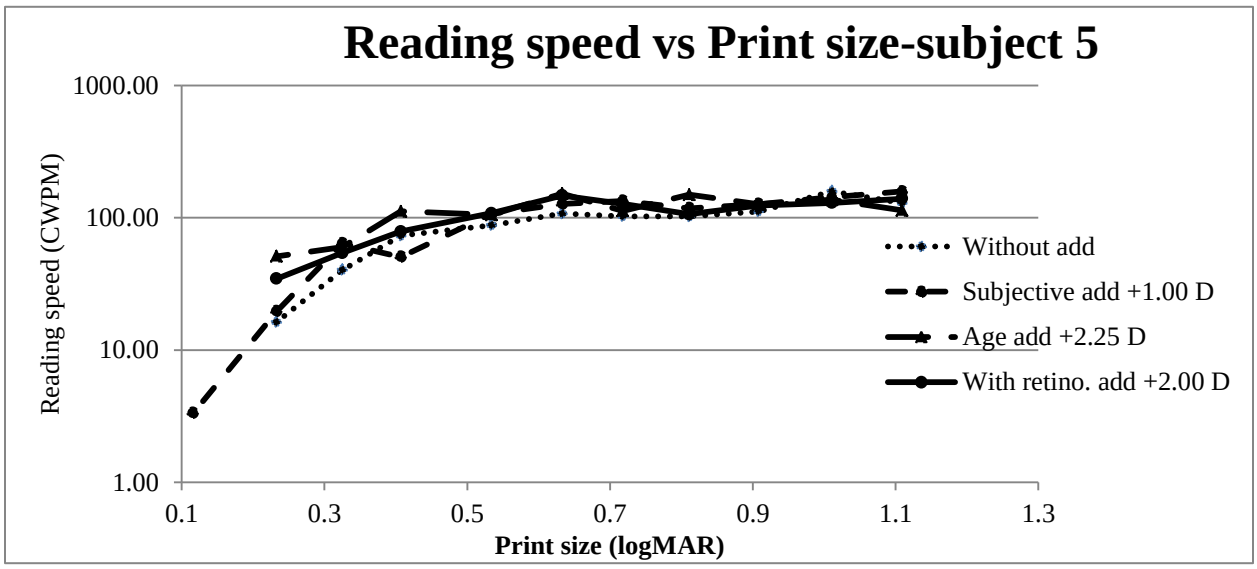
Reading speed against print size with and without reading additions for all the participants.

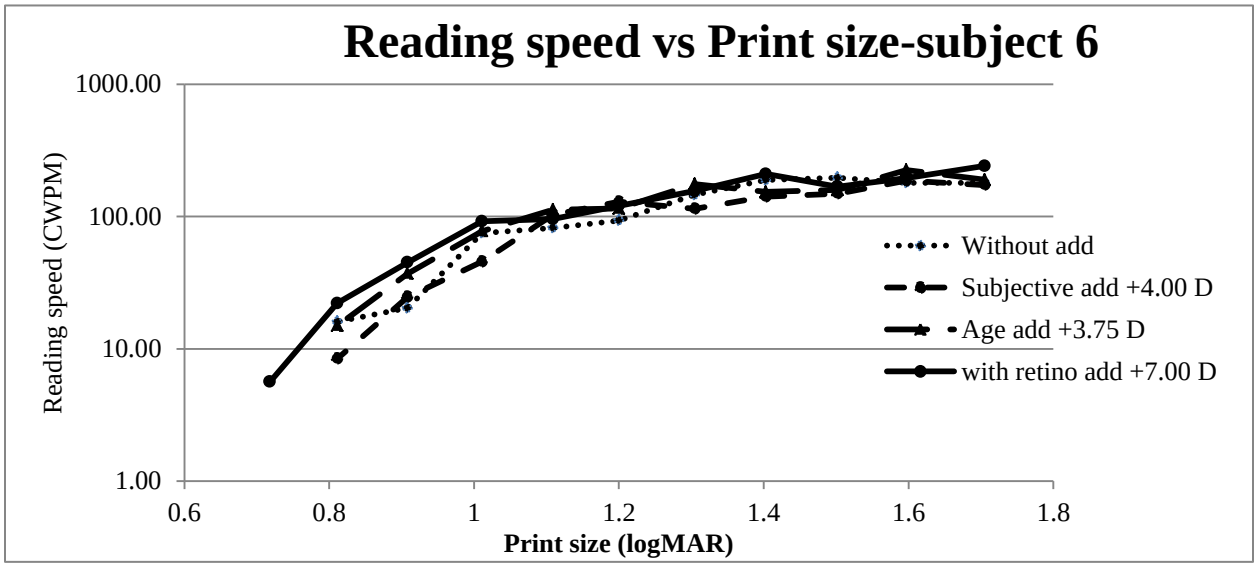


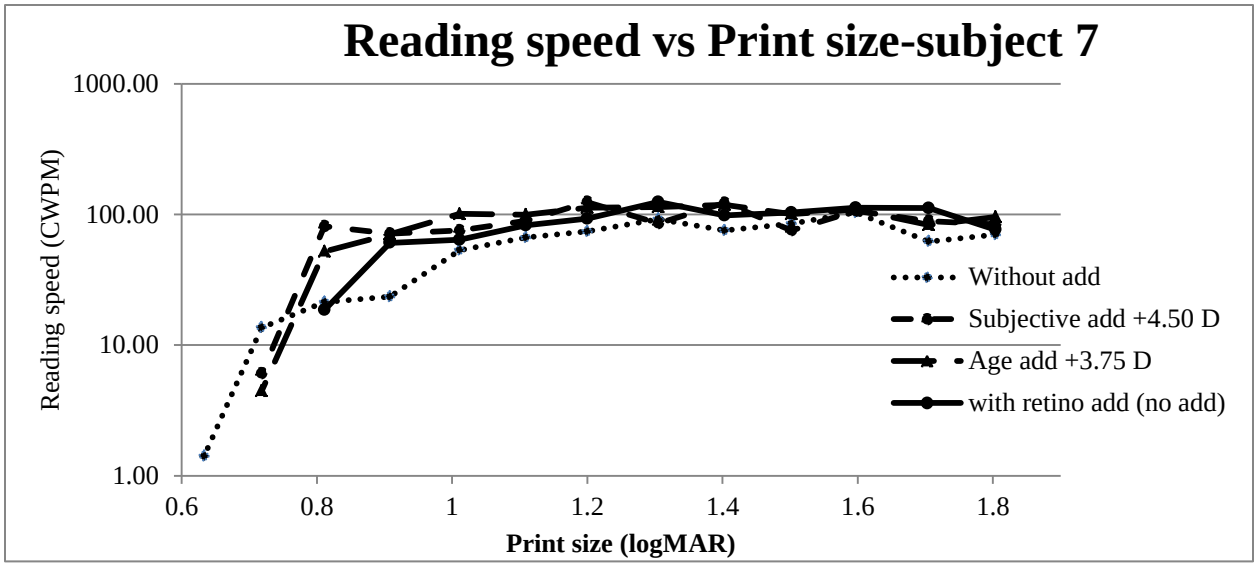


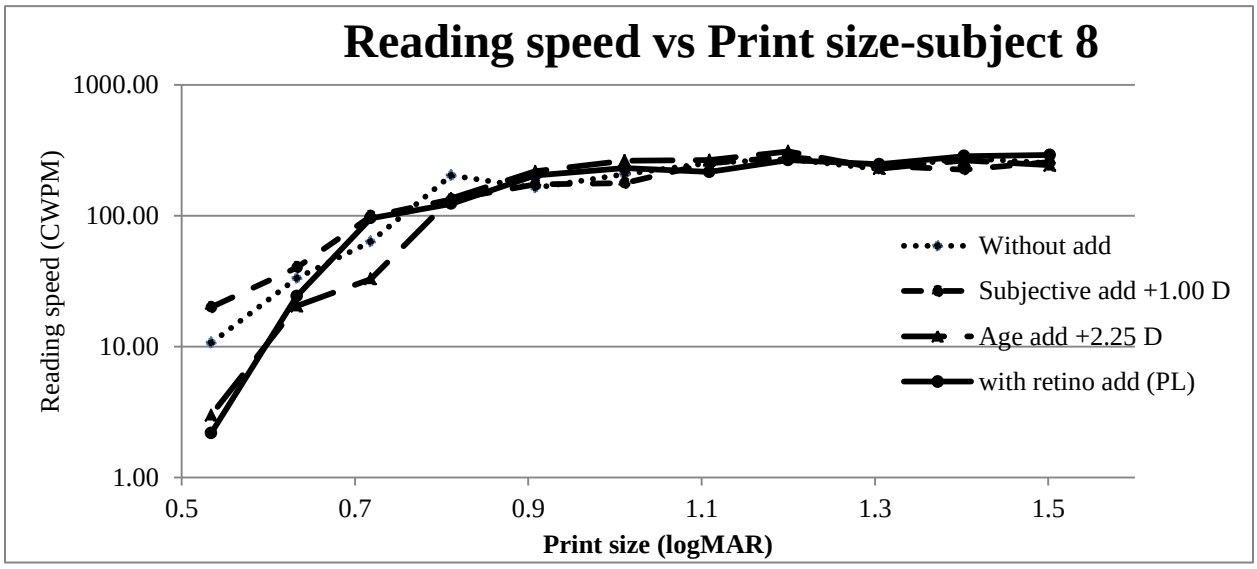

Reading speed vs Print size-subject 3
1000.00
100.00
10.00
1.00
Reading Speed (CWPM)
0.65
0.85
1.05
1.25
1.45
1.65
Print size (logMAR)
Without add
Subjective add +3.00 D
Age add +4.25 D
With retino. add +4.50 D

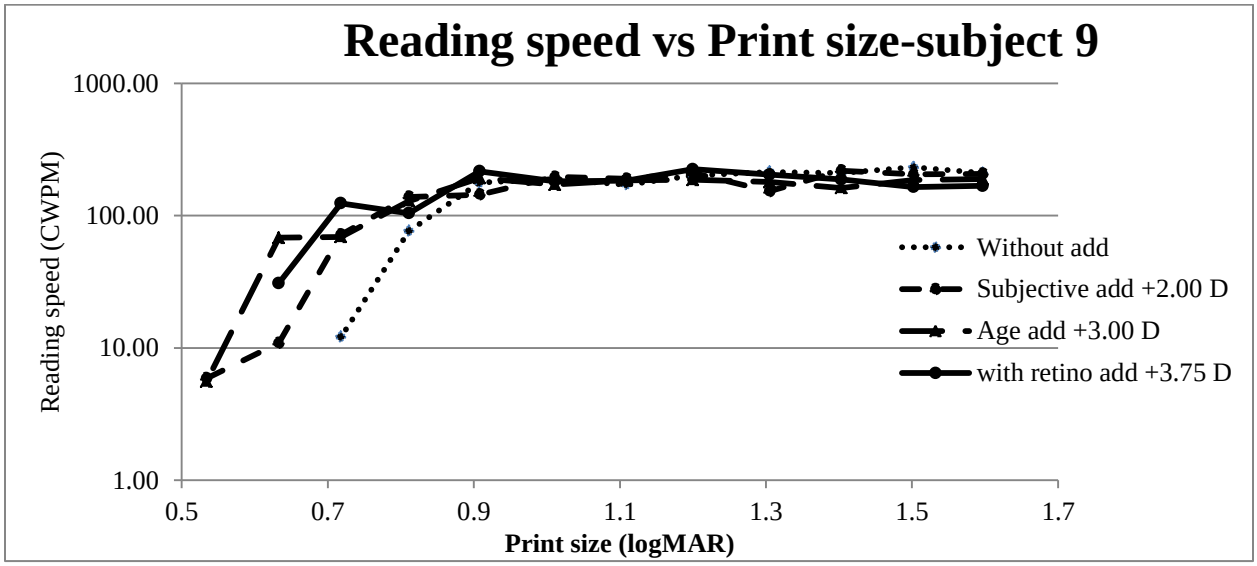

Reading speed vs Print size-subject 4
1000
100
10
1
Reading Speed (CWPM)
0.3
0.5
0.7
0.9
1.1
1.3
Print size (logMAR)
Without add
Subjective add +4.00 D
Age add +2.50 D
With retino. Add +3.00 D

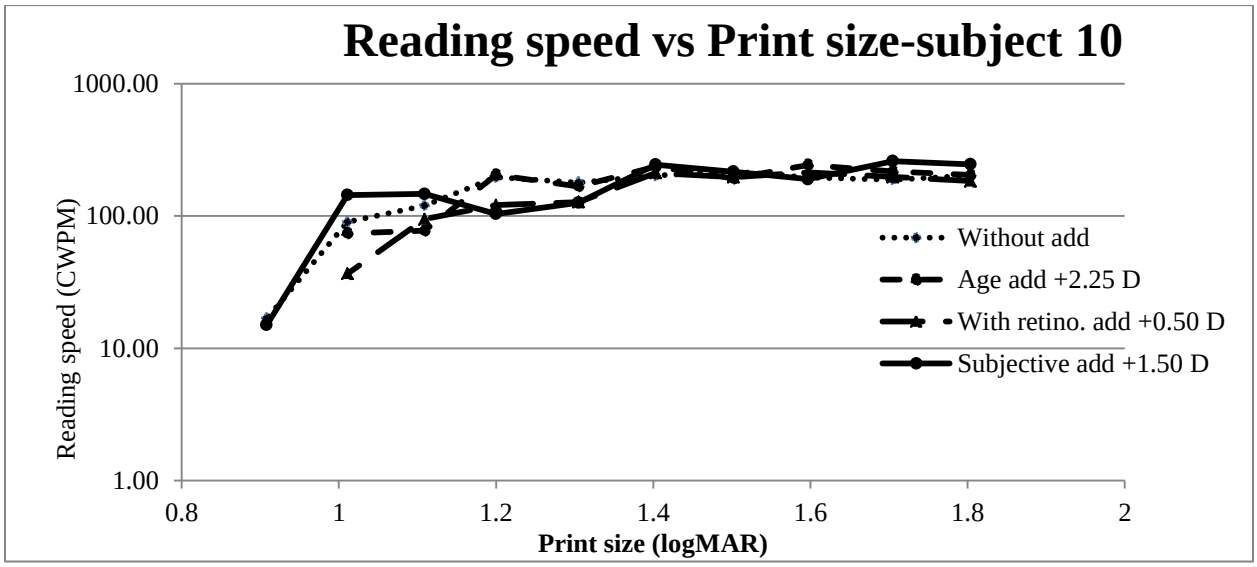

Reading speed vs Print size-subject 5
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.1
0.3
0.5
0.7
0.9
1.1
1.3
Print size (logMAR)
Without add
Subjective add +1.00 D
Age add +2.25 D
With retino. add +2.00 D

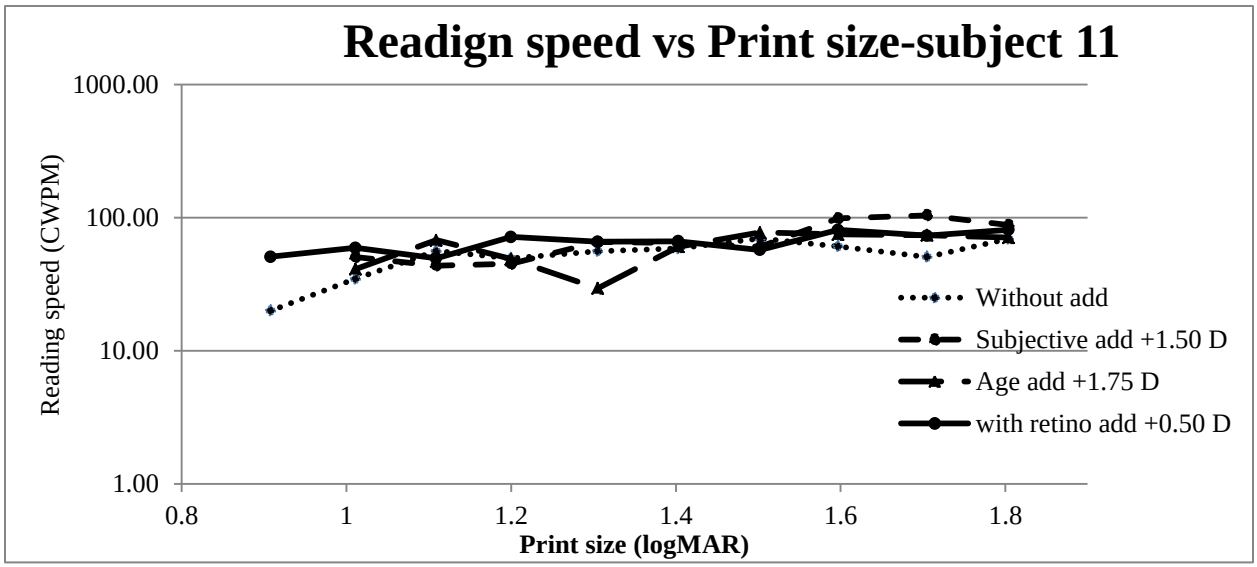

Reading speed vs Print size-subject 6
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.6
0.8
1
1.2
1.4
1.6
1.8
Print size (logMAR)
Without add
Subjective add +4.00 D
Age add +3.75 D
with retino add +7.00 D

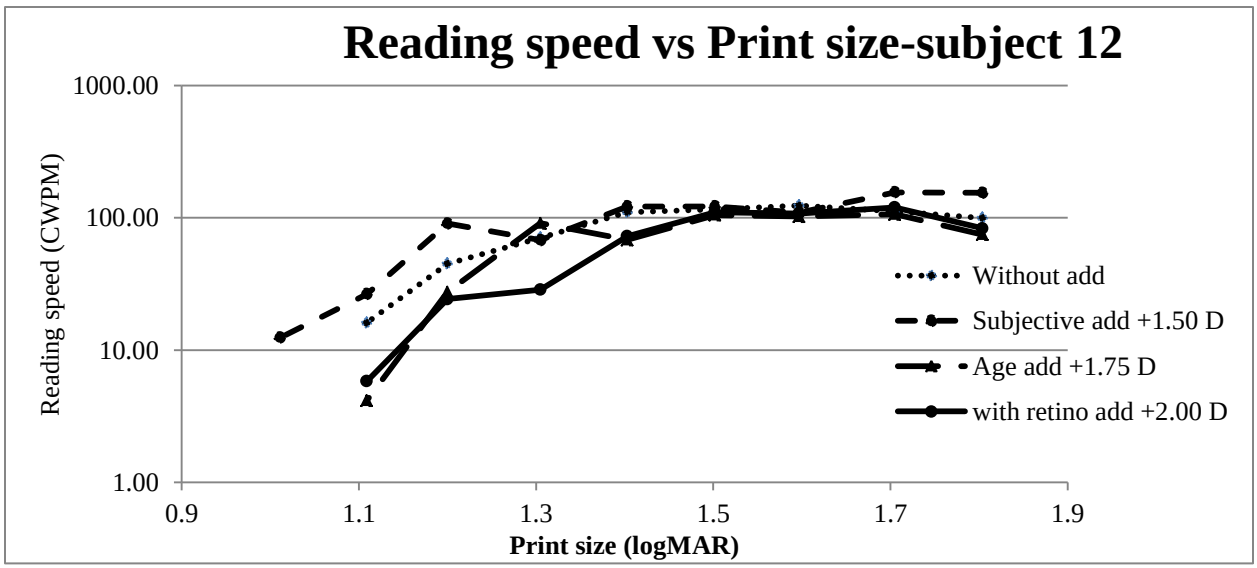

Reading speed vs Print size-subject 7
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.6
0.8
1
1.2
1.4
1.6
1.8
Print size (logMAR)
Without add
Subjective add +4.50 D
Age add +3.75 D
with retino add (no add)

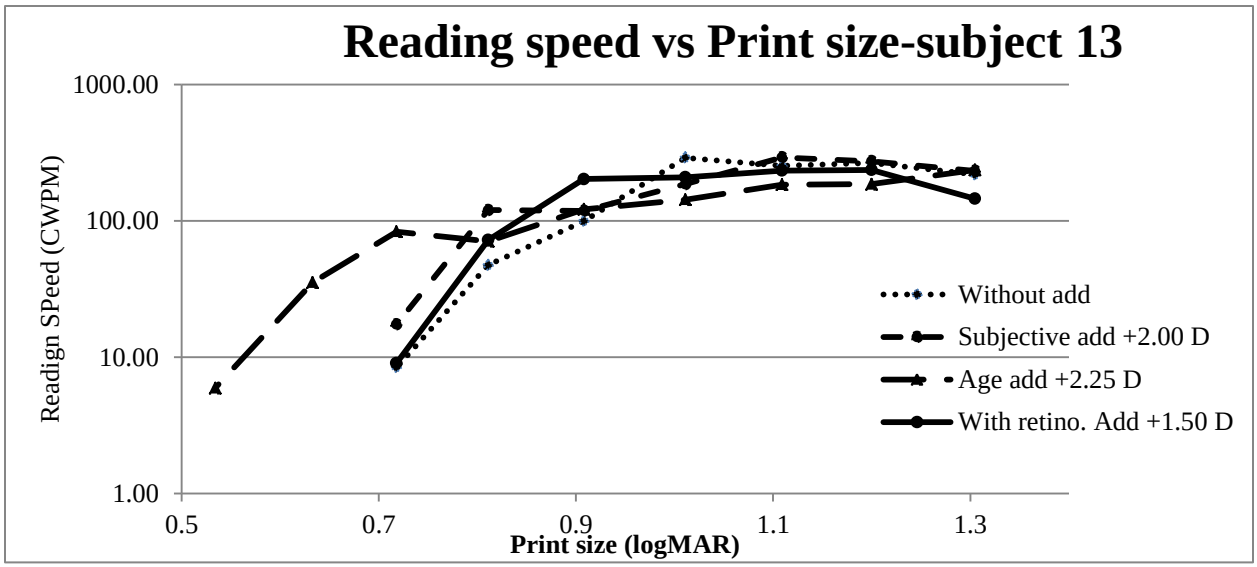

Reading speed vs Print size-subject 8
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.5
0.7
0.9
1.1
1.3
1.5
Print size (logMAR)
Without add
Subjective add +1.00 D
Age add +2.25 D
with retino add (PL)

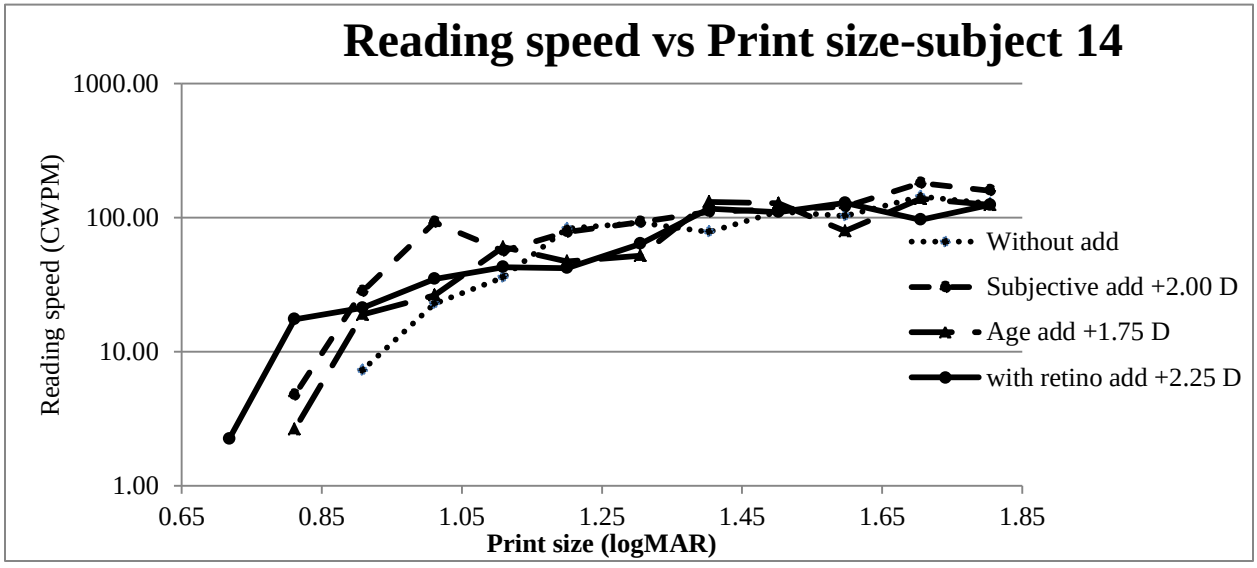

Reading speed vs Print size-subject 9
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.5
0.7
0.9
1.1
1.3
1.5
1.7
Print size (logMAR)
Without add
Subjective add +2.00 D
Age add +3.00 D
with retino add +3.75 D

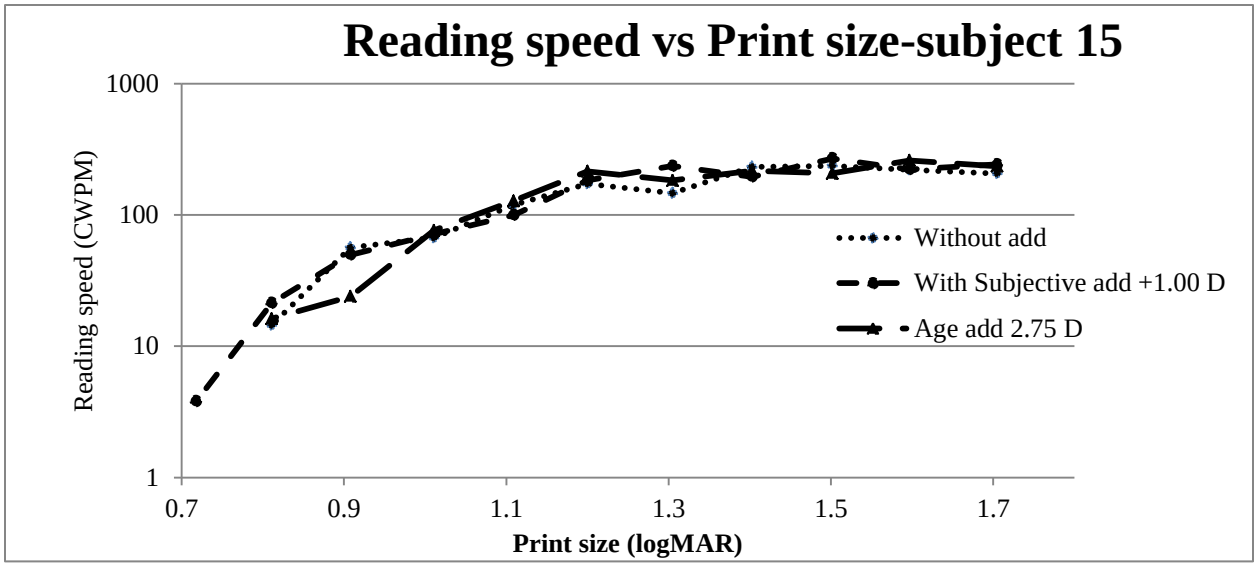

Reading speed vs Print size-subject 10
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.8
1
1.2
1.4
1.6
1.8
2
Print size (logMAR)
Without add
Age add +2.25 D
With retino. add +0.50 D
Subjective add +1.50 D

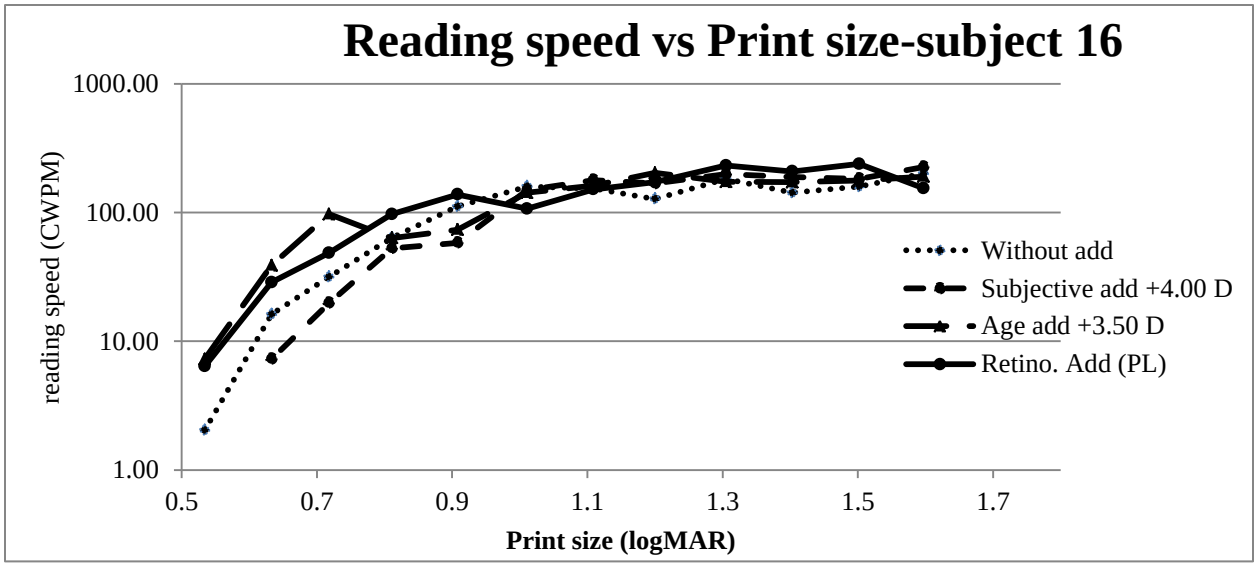

Readign speed vs Print size-subject 11
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.8
1
1.2
1.4
1.6
1.8
Print size (logMAR)
Without add
Subjective add +1.50 D
Age add +1.75 D
with retino add +0.50 D

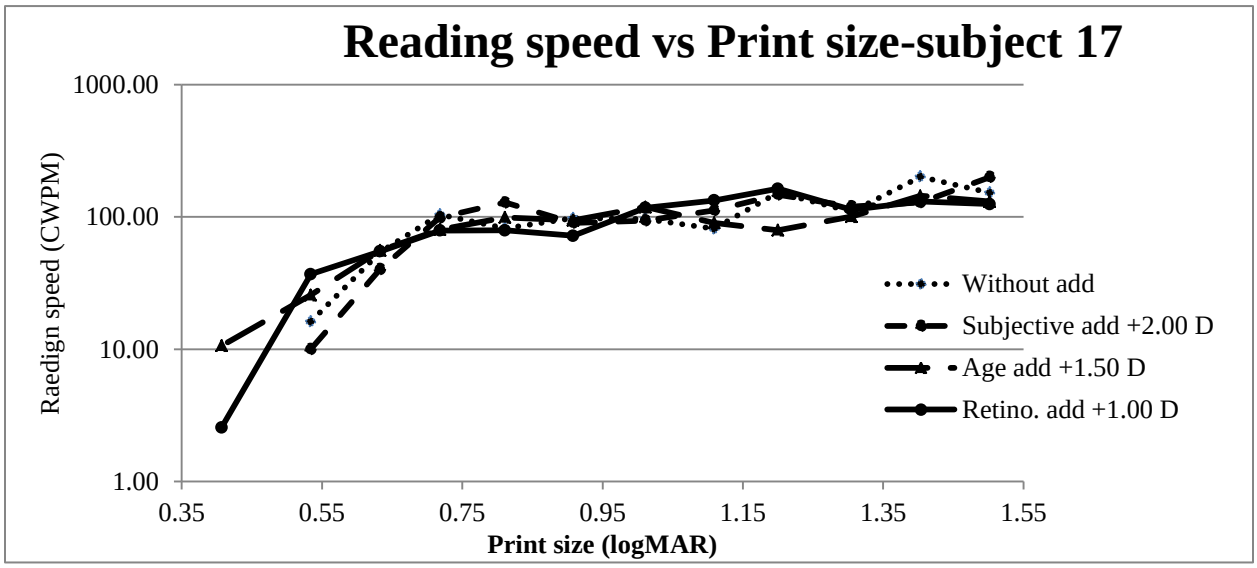

Reading speed vs Print size-subject 12
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.9
1.1
1.3
1.5
1.7
1.9
Print size (logMAR)
Without add
Subjective add +1.50 D
Age add +1.75 D
with retino add +2.00 D

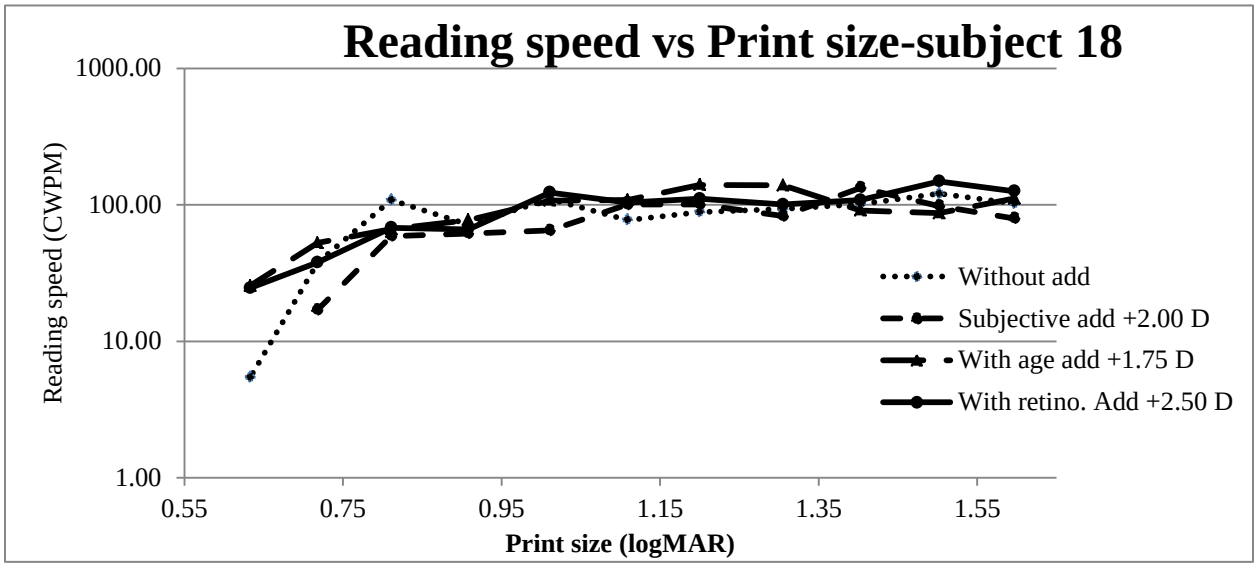

Reading speed vs Print size-subject 13
1000.00
100.00
10.00
1.00
Readign SPeed (CWPM)
0.5
0.7
0.9
1.1
1.3
Print size (logMAR)
Without add
Subjective add +2.00 D
Age add +2.25 D
With retino. Add +1.50 D

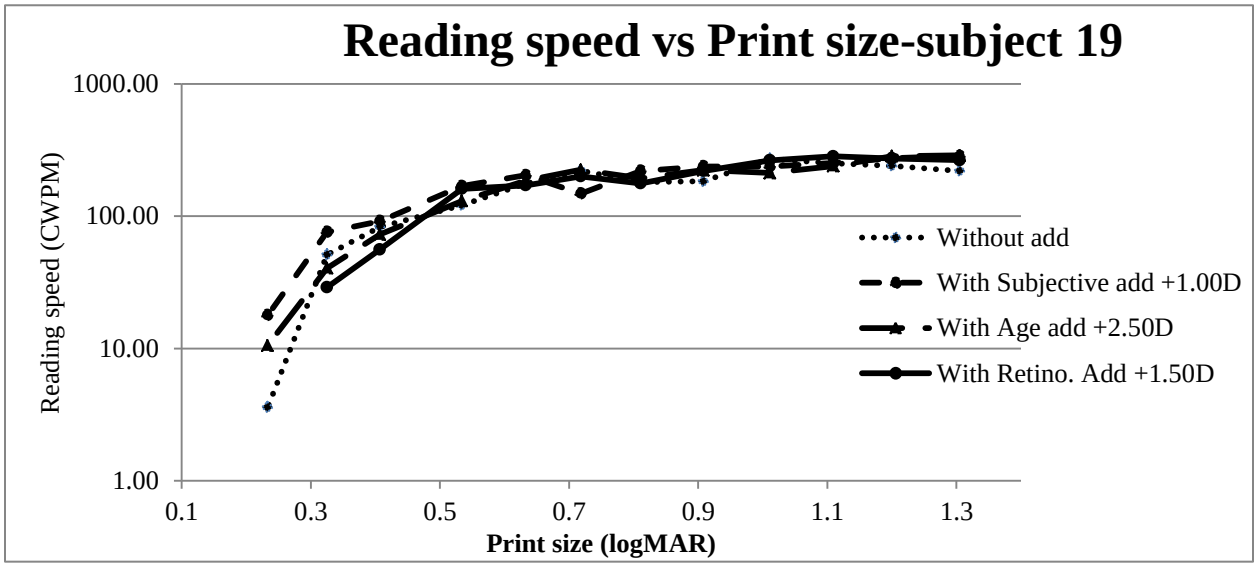

Reading speed vs Print size-subject 14
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.65
0.85
1.05
1.25
1.45
1.65
1.85
Print size (logMAR)
Without add
Subjective add +2.00 D
Age add +1.75 D
with retino add +2.25 D

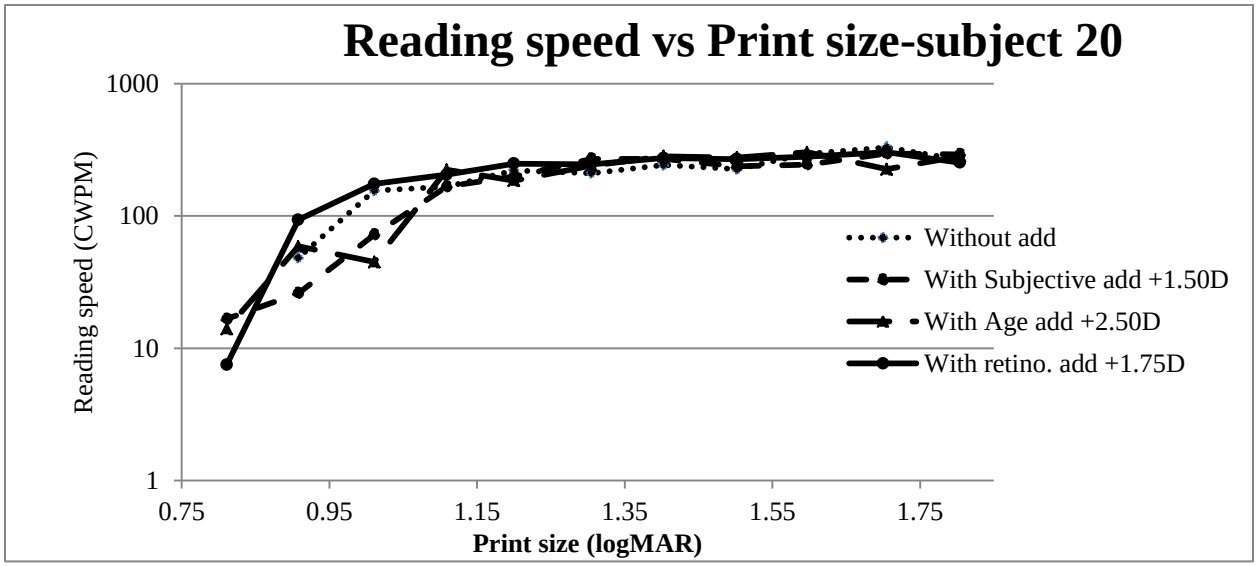

Reading speed vs Print size-subject 15
1000
100
10
1
Reading speed (CWPM)
0.7
0.9
1.1
1.3
1.5
1.7
Print size (logMAR)
Without add
With Subjective add +1.00 D
Age add 2.75 D

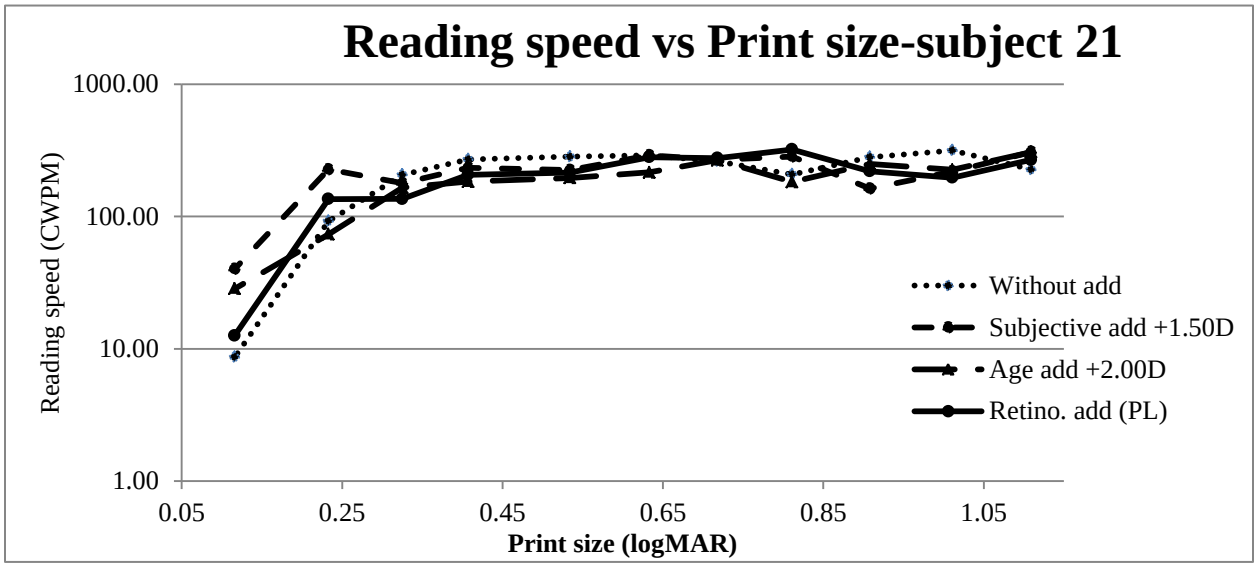

Reading speed vs Print size-subject 16
1000.00
100.00
10.00
1.00
reading speed (CWPM)
0.5
0.7
0.9
1.1
1.3
1.5
1.7
Print size (logMAR)
Without add
Subjective add +4.00 D
Age add +3.50 D
Retino. Add (PL)

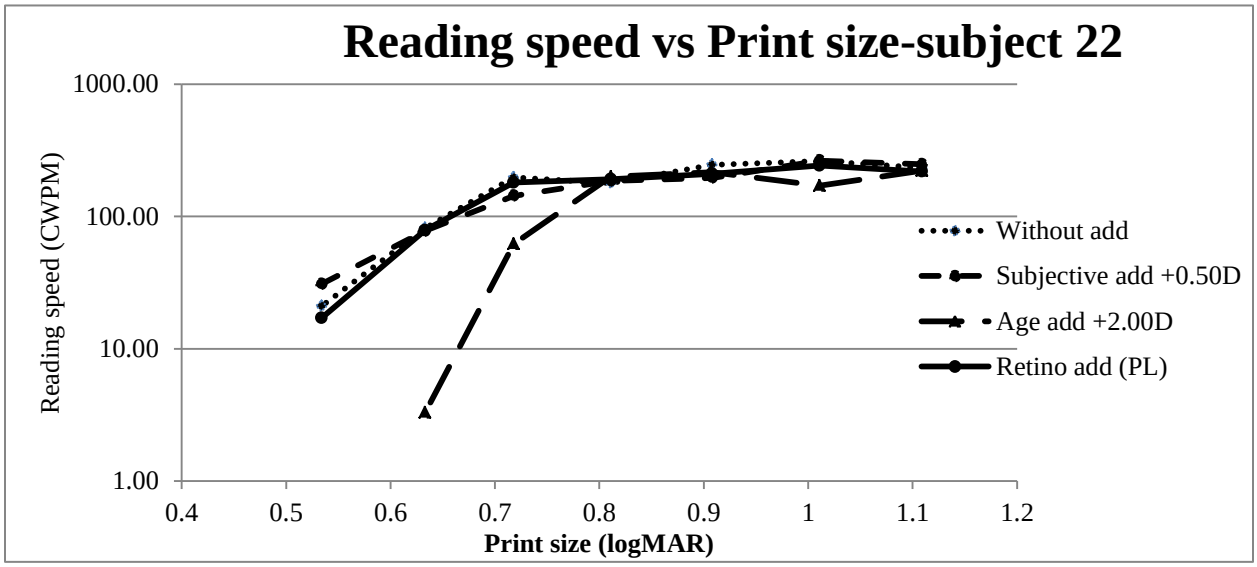

Reading speed vs Print size-subject 17
1000.00
100.00
10.00
1.00
Raedign speed (CWPM)
0.35
0.55
0.75
0.95
1.15
1.35
1.55
Print size (logMAR)
Without add
Subjective add +2.00 D
Age add +1.50 D
Retino. add +1.00 D

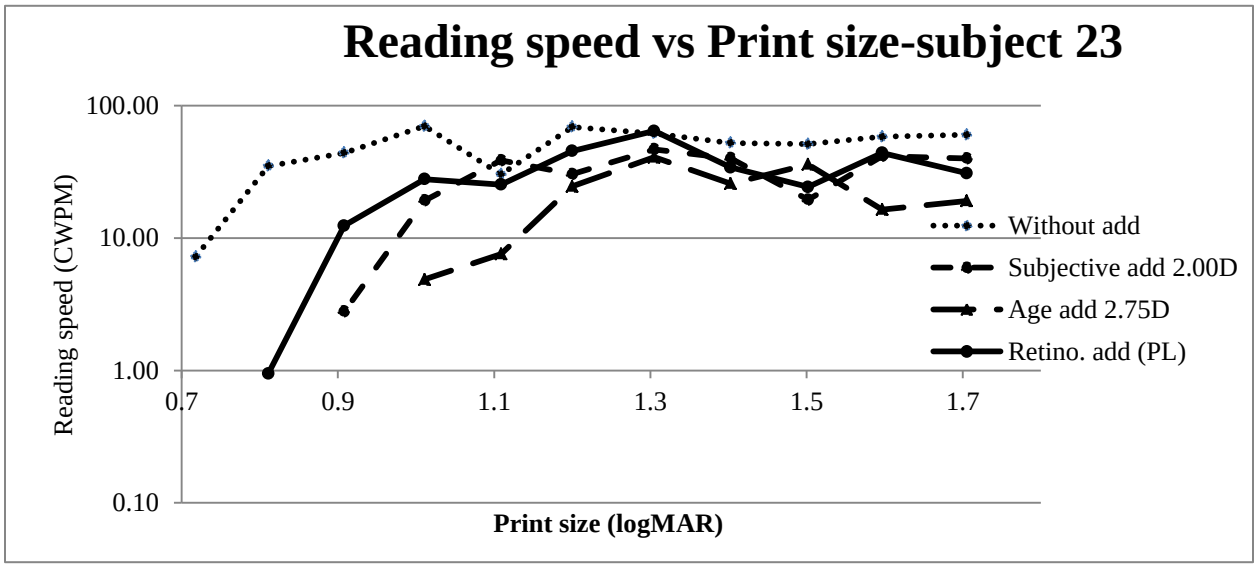

Reading speed vs Print size-subject 18
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.55
0.75
0.95
1.15
1.35
1.55
Print size (logMAR)
Without add
Subjective add +2.00 D
With age add +1.75 D
With retino. Add +2.50 D

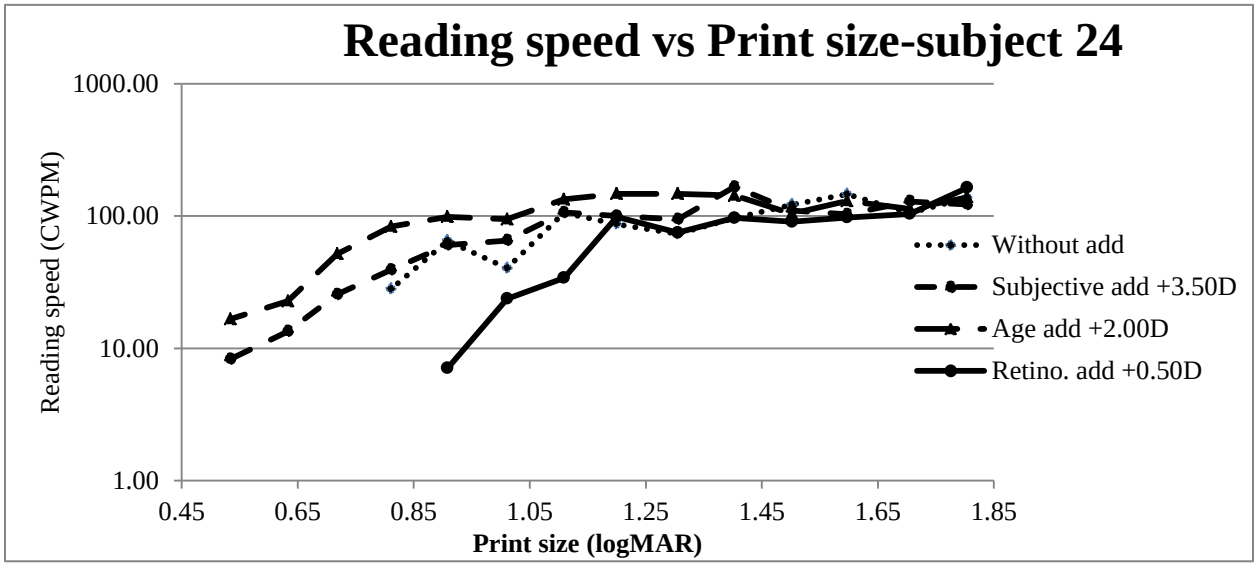

Reading speed vs Print size-subject 19
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.1
0.3
0.5
0.7
0.9
1.1
1.3
Print size (logMAR)
Without add
With Subjective add +1.00D
With Age add +2.50D
With Retino. Add +1.50D

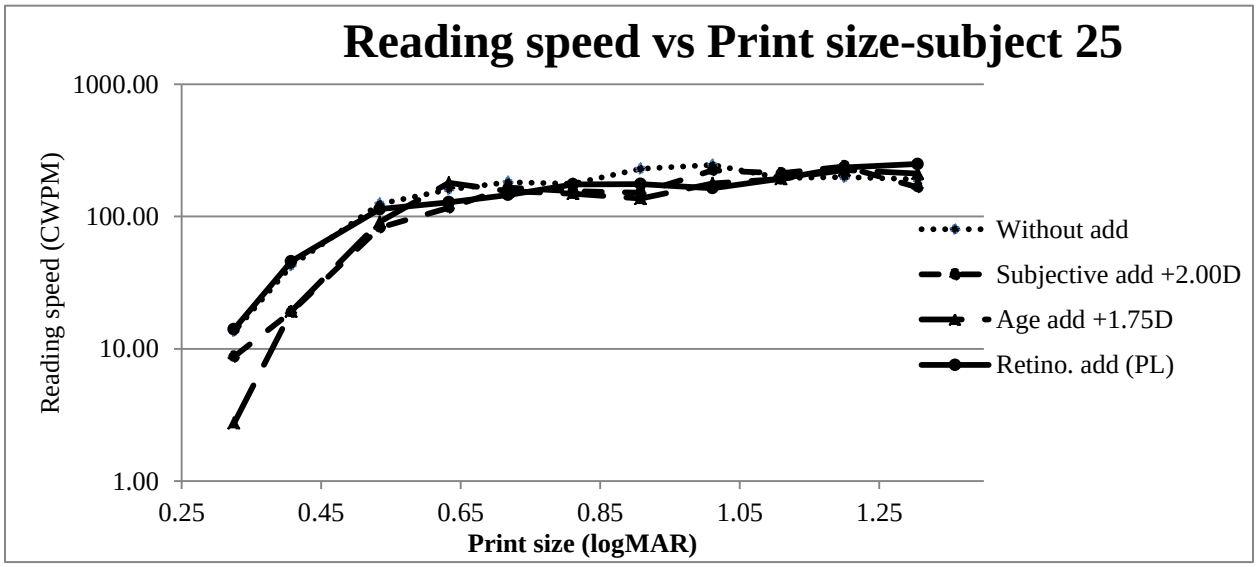

Reading speed vs Print size-subject 20
1000
100
10
1
Reading speed (CWPM)
0.75
0.95
1.15
1.35
1.55
1.75
Print size (logMAR)
Without add
With Subjective add +1.50D
With Age add +2.50D
With retino. add +1.75D

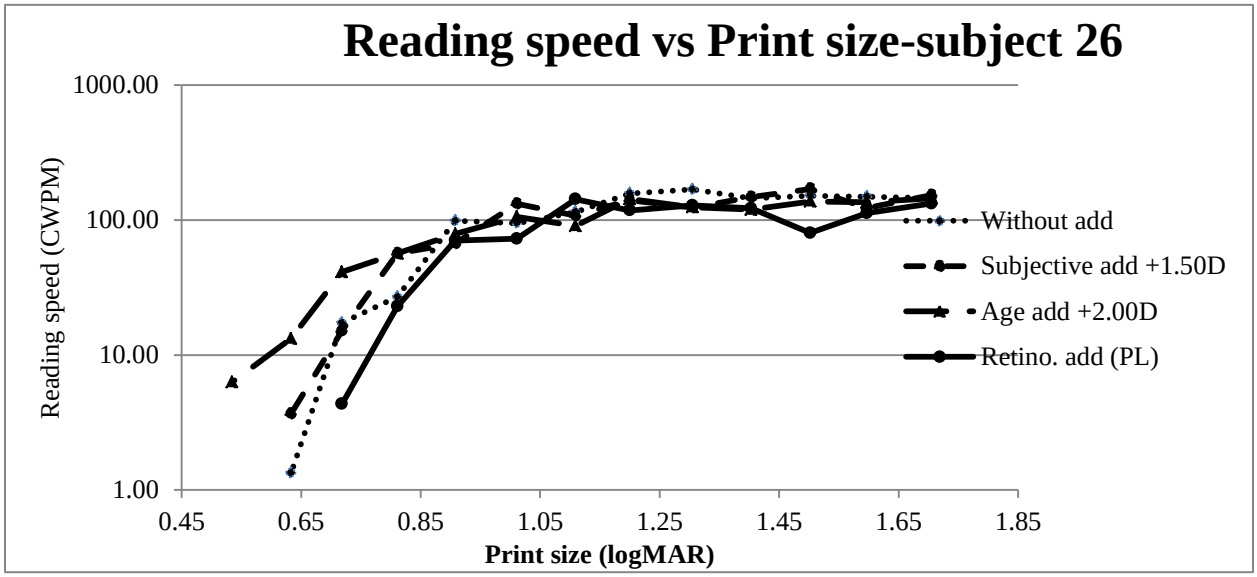

Reading speed vs Print size-subject 21
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.05
0.25
0.45
0.65
0.85
1.05
Print size (logMAR)
Without add
Subjective add +1.50D
Age add +2.00D
Retino. add (PL)

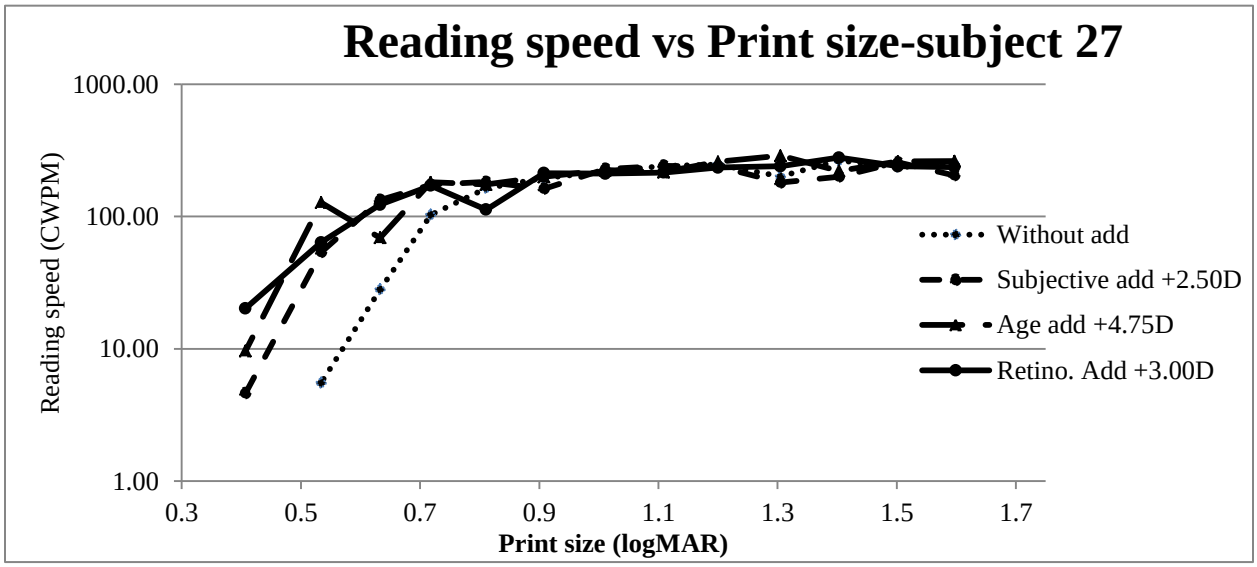

Reading speed vs Print size-subject 22
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
Print size (logMAR)
Without add
Subjective add +0.50D
Age add +2.00D
Retino add (PL)

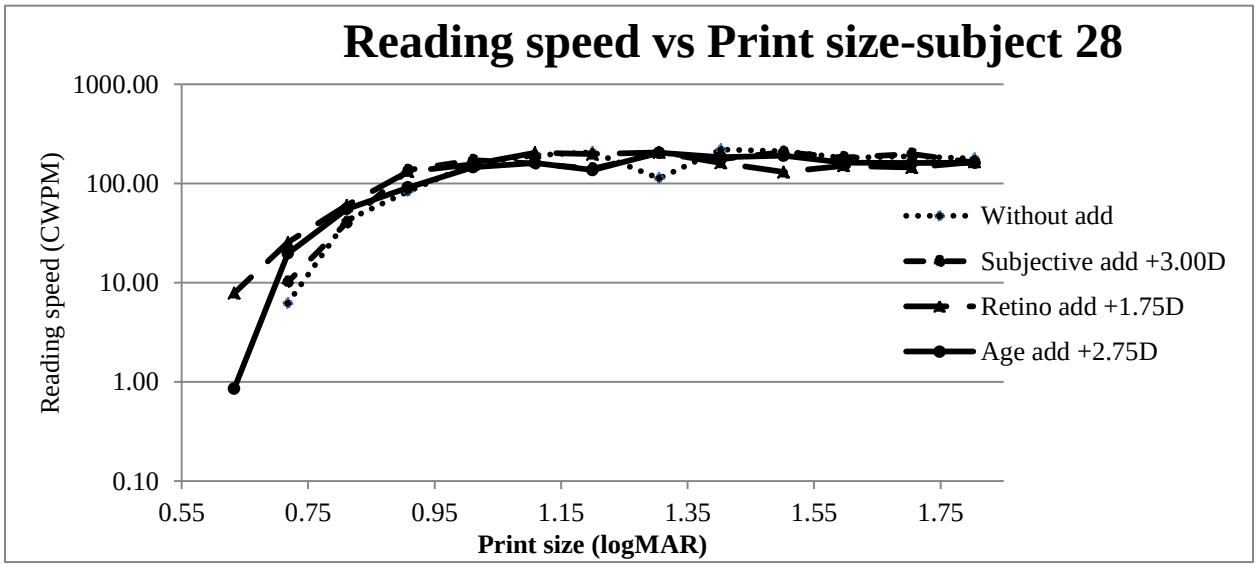

Reading speed vs Print size-subject 23
100.00
10.00
1.00
0.10
Reading speed (CWPM)
0.7
0.9
1.1
1.3
1.5
1.7
Print size (logMAR)
Without add
Subjective add 2.00D
Age add 2.75D
Retino. add (PL)

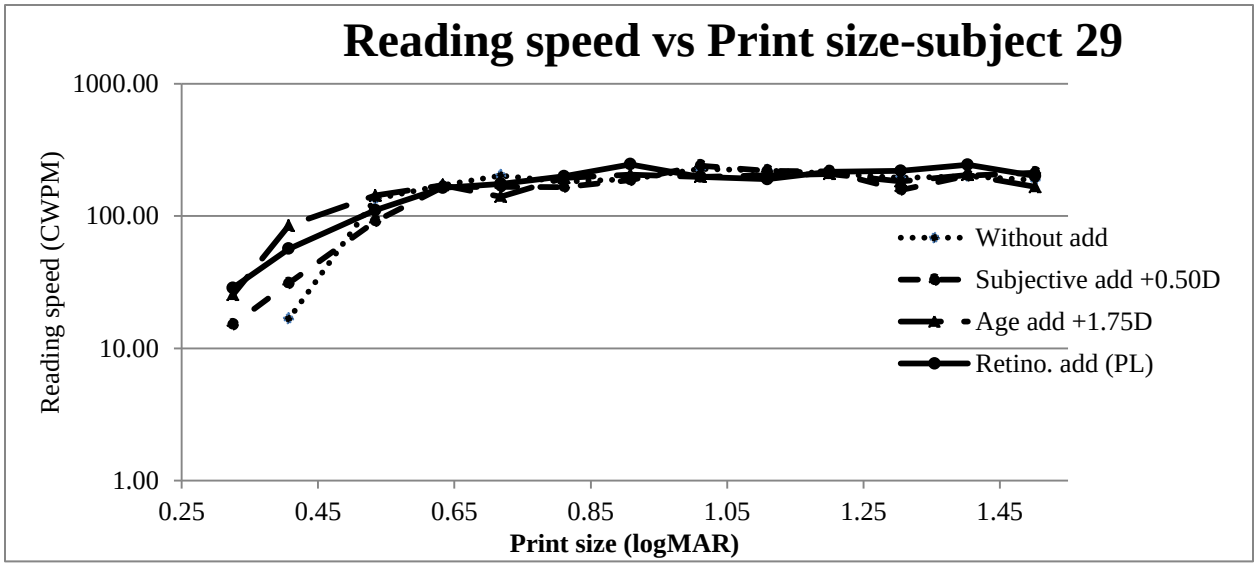

Reading speed vs Print size-subject 24
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.45
0.65
0.85
1.05
1.25
1.45
1.65
1.85
Print size (logMAR)
Without add
Subjective add +3.50D
Age add +2.00D
Retino. add +0.50D

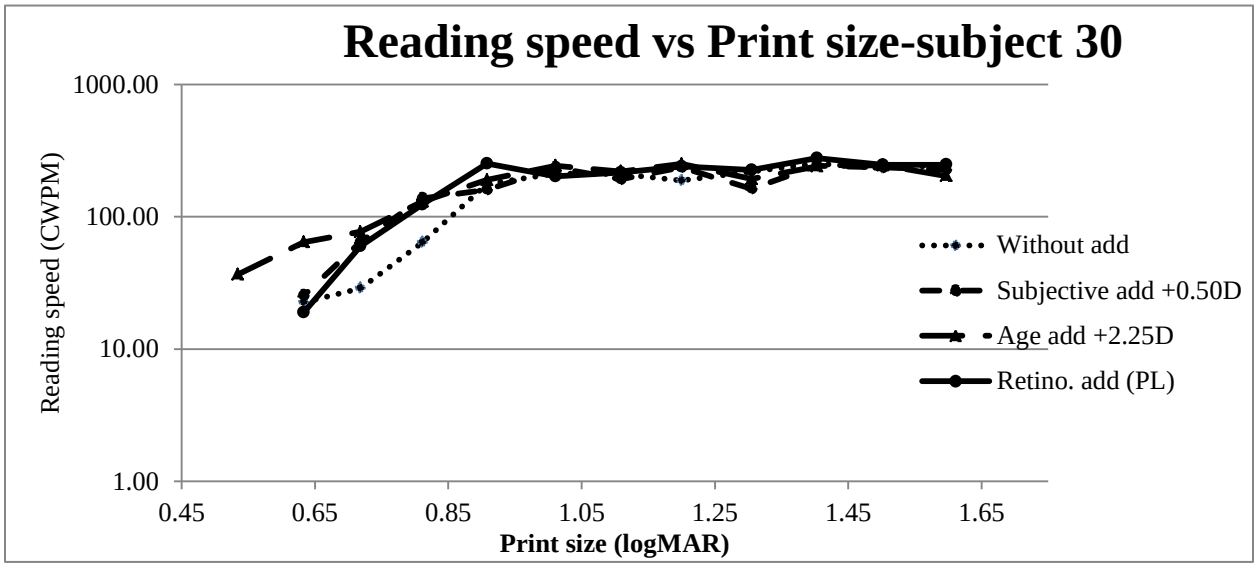

Reading speed vs Print size-subject 25
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.25
0.45
0.65
0.85
1.05
1.25
Print size (logMAR)
Without add
Subjective add +2.00D
Age add +1.75D
Retino. add (PL)


Reading speed vs Print size-subject 26
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.45
0.65
0.85
1.05
1.25
1.45
1.65
1.85
Print size (logMAR)
Without add
Subjective add +1.50D
Age add +2.00D
Retino. add (PL)


Reading speed vs Print size-subject 27
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
Print size (logMAR)
Without add
Subjective add +2.50D
Age add +4.75D
Retino. Add +3.00D


Reading speed vs Print size-subject 28
1000.00
100.00
10.00
1.00
0.10
Reading speed (CWPM)
0.55
0.75
0.95
1.15
1.35
1.55
1.75
Print size (logMAR)
Without add
Subjective add +3.00D
Retino add +1.75D
Age add +2.75D


Reading speed vs Print size-subject 29
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.25
0.45
0.65
0.85
1.05
1.25
1.45
Print size (logMAR)
Without add
Subjective add +0.50D
Age add +1.75D
Retino. add (PL)


Reading speed vs Print size-subject 30
1000.00
100.00
10.00
1.00
Reading speed (CWPM)
0.45
0.65
0.85
1.05
1.25
1.45
1.65
Print size (logMAR)
Without add
Subjective add +0.50D
Age add +2.25D
Retino. add (PL)