Reading with a Loss of Central Vision

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Declaration of Authorship

I, Farah Akthar, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed: Farah Akthar

Date: January 2021

Abstract

Central vision loss is a common condition arising most often in people with macular degeneration. Presenting text dynamically as scrolling and rapid serial visual presentation (RSVP) formats may be useful ways of supporting reading for this population by enhancing the use of eccentric viewing. This thesis includes a combination of laboratory experiments, using a simulated central vision loss, and comparable studies in people with actual central vision loss caused by macular degeneration. The aim was to provide a detailed examination of reading performance with central vision loss, with static and dynamic text formats. The benefits of perceptual learning (training) and the inclusion of biofeedback to support the use of eccentric viewing was also examined. Finally, qualitative measures were obtained from people with macular degeneration to evaluate the potential of scrolling text to support reading with a central vision loss. Laboratory studies indicated that: (i) reading performance was better with the scrolling text display compared to RSVP and static text; (ii) auditory biofeedback had small effects on improving reading performance and the maintenance of eccentric viewing; (iii) training did however produce significant improvements in reading performance with the scrolling text format. Studies of individuals with macular degeneration showed that: (i) reading performance was better with scrolling text compared to RSVP and static formats; (ii) practicing with scrolling text for 4 weeks resulted in large improvements in reading performance; (iii) and the majority of participants reported positive experiences of reading with scrolling text. Overall, the use of scrolling text and training can improve reading performance in people with a central vision loss and the use of modern technology such as tablets offer great potential for people with central vision loss.

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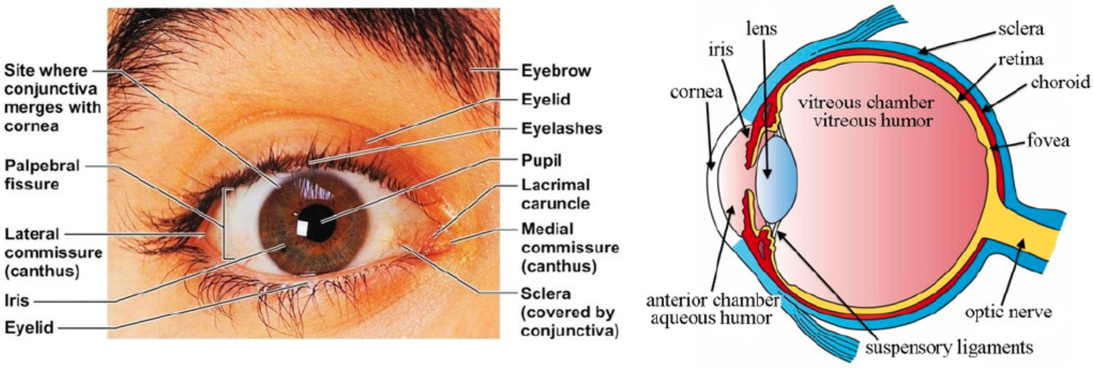
Chapter 1.

Background and Overview

The human eye is a specialised sense organ that focuses light onto the retina - a light sensitive membrane. In order to produce our sense of vision, light must travel through numerous structures of the eye including the cornea, anterior chamber, pupil, lens, vitreous body and finally the retina (see Figure 1). The retina is a thin layer of tissue, approximately 0.5 millimetre (mm) thick that lines the back of the eye which is situated near the optic nerve (Kolb, 1995). It transforms light into neural signals by converting light photons into a biochemical message which can be translated into an electrical signal to activate the succeeding neurons of the retina to be sent to the brain for visual processing (Kolb, 1995). The retina is comprised of two primary layers named the retinal pigment epithelium (RPE); situated between the vascular structures (Eggers, 1961); vessels of the choriocapillaris and the choroid, functioning to nourish and protect the retina, eliminate waste products and ensuring no new blood vessels grow into the retina therefore, networking with the photoreceptors in the sustainment of visual function (Kolb, 1995; Strauss, 2005). If the RPE deteriorates, as in the case with age-related macular degeneration (AMD), this will result in disturbed vision as a consequence of the dysfunction of the neurosensory retina; the second primary layer (Eggers, 1961).

Figure 1

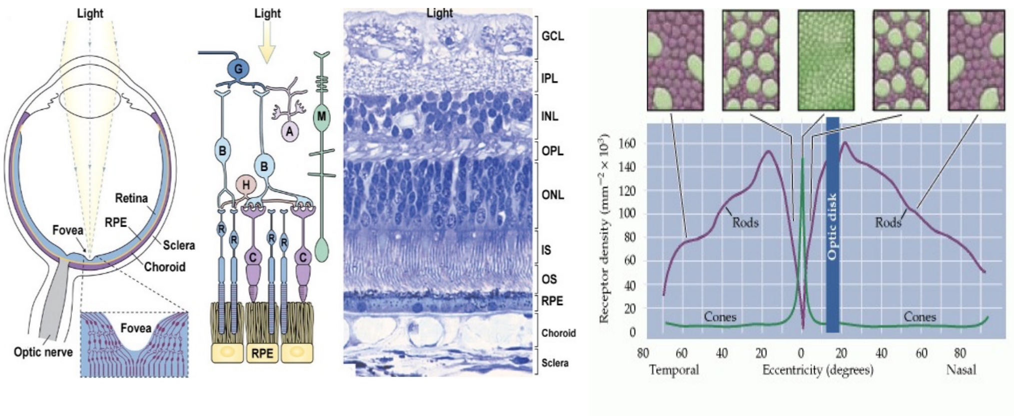
Anatomy of the human eye, including retina, macula and fovea (George, 2019).



The retina is comprised of eight layers (see Figure 2) including a layer of photoreceptor cells. There are two different types of photoreceptor cells; rod cells and cone cells (see Figure 2) distinguished by their shape, retinal location and arrangement of synaptic connections (Mustafi1 & Engel, 2008). The rods (roughly 91 million cells) are concentrated in the outer parts of the retina and are specialised for dark adapted vision (scotopic vision) (Purves et al., 2001). The rods are responsible for providing the low spatial resolution vision (low acuity) and are particularly sensitive to light thus function best in low levels of luminance, motion detection and provide black and white vision. The cones (roughly 4.5 million cells) are, by contrast, responsible for colour vision and for detailed high-acuity vision and spatial resolution (Purves et al., 2001). The cone photoreceptor cells are most optimal in bright light and are predominantly found in the centre of the macula (around 5.5mm) of the retina called the fovea (1.5mm wide, 0.4mm in diameter). The fovea is located in the centre of the macula, where the greatest visual acuity is acquired.

Figure 2

Left - Diagram displaying the eight layers of the human retina and the distribution of the rod and cone photoreceptors. Right - displays the change of photo receptor density across the retina (Hill, 2021).



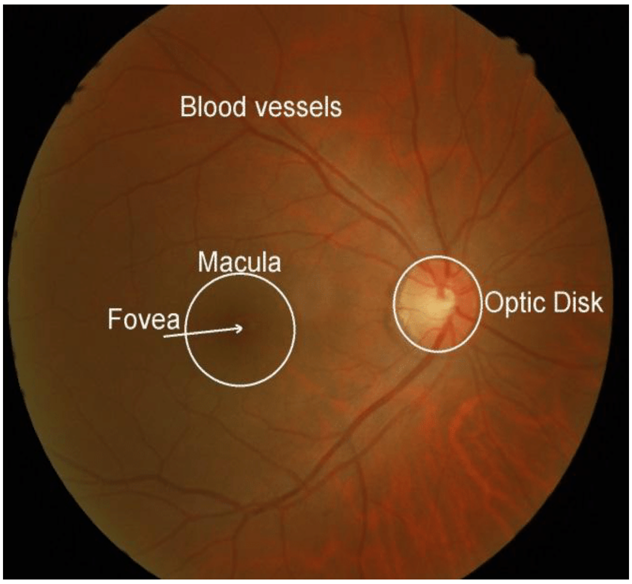
Macula and Fovea

The macula comprises of the entire foveal area (see Figure 3), including the foveal pit (1.5mm wide), foveal slope, parafovea and perifovea taking up a total area of less than 1mm^2 (Kolb, 1995). The macula is located in the central, posterior area of the retina and includes the greatest concentration of cone photoreceptor cells with increased resolution and visual acuity. The macula is accountable for high visual acuity thus permitting an individual to see fine details such as letters for reading (Cheung & Eaton, 2013). The yellow pigmentation of the macula area (called the macula lutea) is a consequence of the yellow screening pigments from the xanthophyll carotenoids, zeaxanthin and lutein in the cone axons of the Henle fibre layers. The macula lutea behaves as a small wavelength filter, supplementary to that contributed by the lens (Kolb, 1995). The fovea is arguably the most important part of the retina for human vision. The fovea is observed as a tiny pit (which is observed to be smaller than the whole macula) comprising of highly concentrated, maximum density cone photoreceptor cells without any rod photoreceptors.

The fovea is responsible for providing vision with the highest possible detail and acuity. The cone photoreceptor cells in the fovea are organised at their most structured packing density as a hexagonal mosaic (Kolb, 1995).

Figure 3

Displays a fundus image of a healthy 'normal' retina and the location of the macula, fovea, optic disk and blood vessels (Basit & Egerton, 2013).



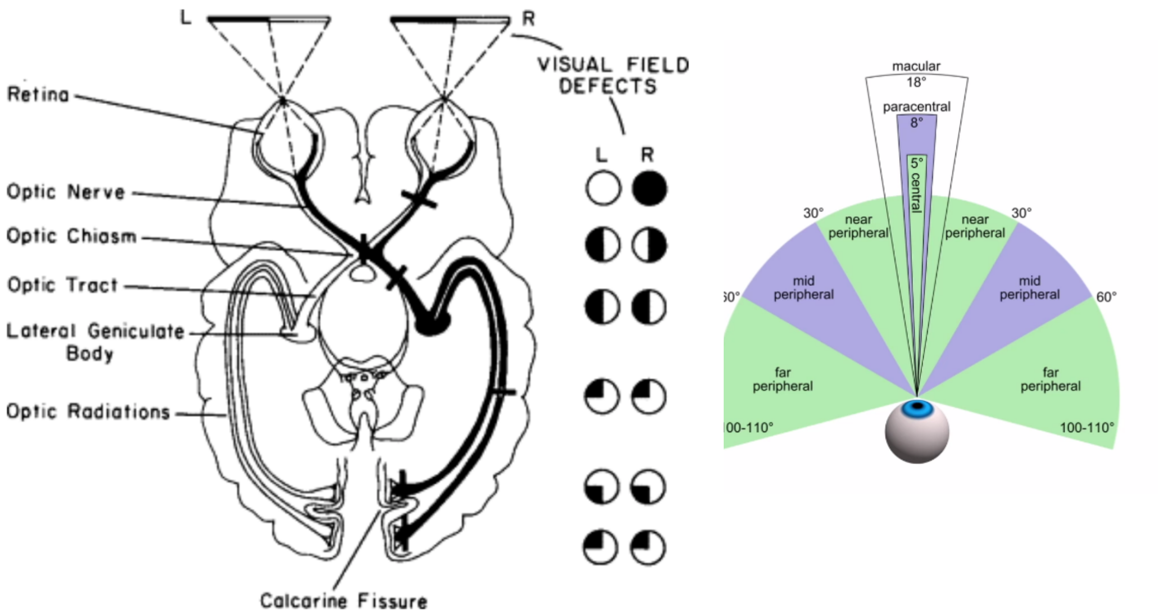
The fovea is the area of high acuity vision, comprising of the central 2^{o} of vision, followed by the parafoveal which lengthens out to 5 ^{o} on each side of the fixation (see Figure 3), the vision in the parafoveal is poorer than the foveal region. The periphery has the lowest resolution area of vision, as this extends beyond the parafoveal region. However, the components of the visual stimulus in parafoveal (peripheral) vision determines the initiation of an eye movement called a saccade (Wurtz, 2000) to identify the stimulus (Rayner, 1975). For instance, during reading, a word which is displayed in parafoveal vision is identified more rapidly and accurately than in situations where a preview is not possible (Jacobs, 1986; Morrison & Rayner, 1981). Conversely, if a large object or a large sized word is presented in the periphery, this can be determined without the need of a saccade (Pollatsek et al., 1984). Therefore, eye movements are necessary to compensate for these differences (see section on 'Eye movements and vision'). It is evident that the visual field can be separated into regions where a stimulus can be determined without the need to make an eye movement, where an eye movement is necessary in order to determine the stimulus and the need to make a head movement to determine the stimulus (e.g. Sanders & Van Duren, 1998).

Human vision

The human visual pathway (comprising of numerous cells and synapses) characterises the anatomical pathway by which electrical signals (visual information from the environment) developed by the retina are sent directly to the brain for visual processing (Remington, 2012). The cornea directs the image onto the retina and the lens located behind the cornea (see Figure 1) transforms the image top to bottom. The retina itself converts the light into nerve signals, allowing us to see in the dark, in sunlight, with colour vision and to view things with an increased visual acuity. The medial retinal layer of the retina consists of three different nerve cells: bipolar, horizontal and amacrine cells. The bipolar cells obtain input from the photoreceptors and focus this input into the retinal ganglion cells (situated in the inner retina). The horizontal cells connect the receptors whilst the bipolar cells form considerably long connections that can be aligned to the retinal layers. Finally, the amacrine cells function to connect the bipolar cells and the retinal ganglion cells. The axons of the retinal ganglion cells traverse the surface of the retina and accumulate in a group at the optic disk to exit the eye and devise the optic nerve (Erskine & Herreral, 2015). The optic axons from both eyes converge at the optic chiasm, situated at the base of the hypothalamus (see Figure 4). Here, the retinal ganglion cell axons from the nasal retina branch to opposite sides of the brain (contralateral axons), whereas the temporal retina project ipsilateral to their hemisphere of origin (see Figure 4) (Remington, 2012).

Figure 4

Image on the left represents a schematic diagram showing the human visual pathway from the left and right eye and visual field defects (Love & Webb, 1992). The image on the right displays the sections in the central and peripheral vision (Lungaro et al., 2018).

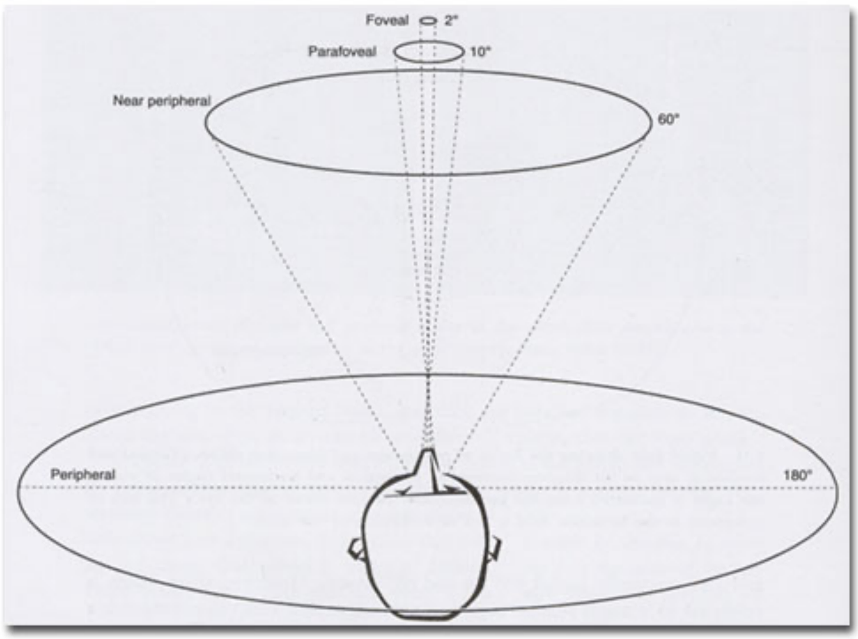


Eye movements and Vision

The human eye movement system is designed to make the best use of the retina and the primary visual cortex (early visual system) with individual fixations being made on the fovea, the greatest acuity of vision. The visual field can be partitioned into three areas; foveal, parafoveal and peripheral (see Figure 5).

Figure 5

Schematic diagram displaying degrees of the foveal area, parafoveal, near peripheral and peripheral regions (Solso, 2002).

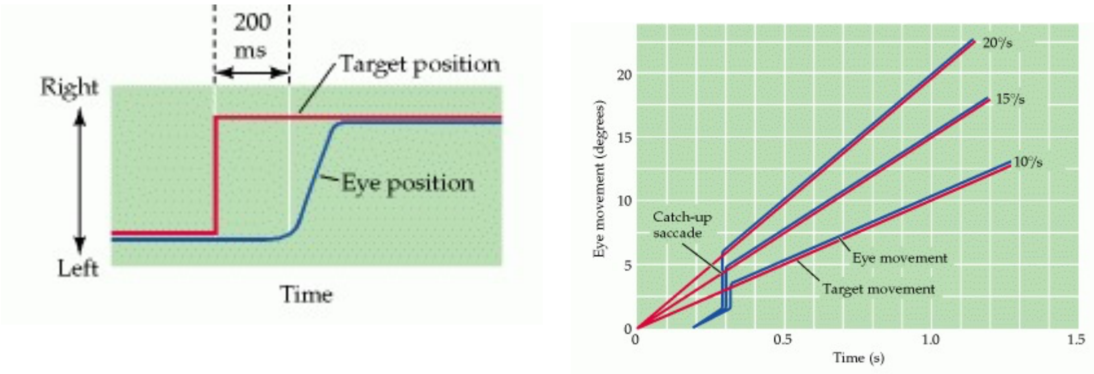


Eye movements

In order to view the world, a technique of 'saccade and fixate' is adopted, whereby information is accumulated during stabilised fixations and saccades are used to move gaze in a different direction in a rapid manner (Land, 2011). Fast saccadic eye movements are made due to acuity limitations and to bring part of the visual scene that is of interest into focus on the foveal area of the retina for detailed visual analysis (Wurtz, 2000). Saccades are alternated with fixations (short pauses where the eyes remain still). There are four basic types of eye movements: saccades are fast, ballistic movements of the eyes that rapidly change the point of fixation. Saccades differ in their amplitude, from small movements (for example, during reading) to large movements (for example, looking around a room). Saccades are a voluntary movement, but transpire reflexively when the eyes are open and occur even when the eyes are fixated on a target (Liversedge & Findlay, 2000). Figure 6 displays the time at which a saccadic eye movement occurs – when a stimulus appears in the periphery, a saccade takes approximately 200 milliseconds (ms) to initiate. The region of the stimulus with respect to the fovea is calculated and the intended position (also referred to as motor error) is translated into a motor command which stimulates the extraocular muscles to change the position of the eyes. It is also important to note the role of saccadic suppression, whereby the visibility of a stimulus is declined instantly initially, during and 80-100ms after a saccadic eye movement (Rubin & Turano, 1992).

Figure 6

Left - displays the metrics of a typical saccadic eye movement. The red line shows the step-change of a visual target and the blue represents the change of eye position. A delay of around 200 milliseconds represents the latency of the movement. Right - displays the metrics of a smooth pursuit eye movement. The blue lines indicate the movements of the eyes and the red lines indicate the tracking of the target at three separate velocities. A saccade is made to locate the target allowing the velocity of the target and movement of the eyes to be identical (Purves, Augustine, Fitzpatrick et al., 2001).



Smooth pursuit eye movements (see Figure 6) are slower tracking eye movements made to ensure a moving stimulus (for example, a moving car) is kept focused on the fovea. Smooth pursuit eye movements are voluntary as the individual can choose whether or not to track the stimulus that is moving. If eye movements change between fast and slow in response to a moving stimulus this may result in optokinetic nystagmus. This is a typical reflexive response of the eyes as a result of large-scale movements which occur in the visual scene (Purves et al., 2001). Vergence movements aim to shift the fovea of both eyes onto the stimulus to account for distance from the observer. These types of eye movements are disconjugate which require a convergence or divergence of each eye to provide lines of sight to observe a target located in depth. Vestibulo-ocular movements are made to stabilise the eyes in relation to the external world therefore, adjusting for the movements of the head. This reflex response is necessary to avoid images from the visual world shifting on the surface of the retina as the head position alters. The vestibular system itself identifies short, temporary alterations in head position and generates fast corrective eye movements (Purves et al., 2001).

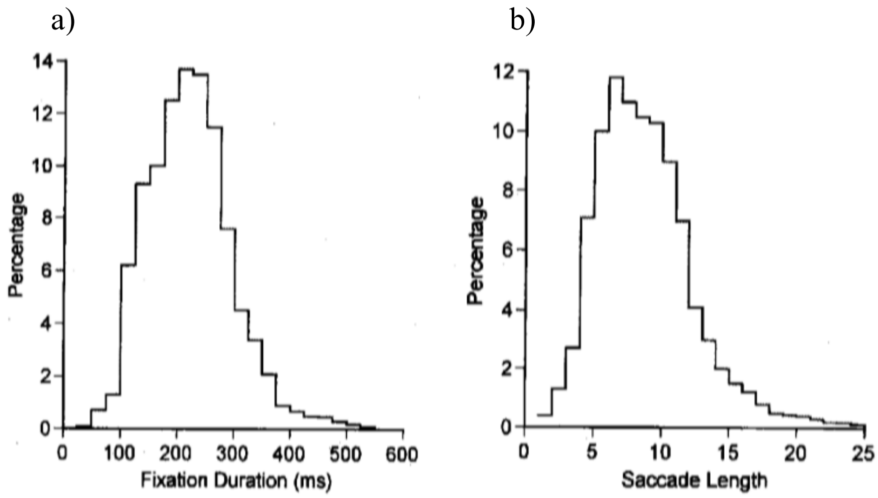
Eye movements during reading

For reading, which relies on high visual acuity to allow for letter discrimination, the sequence of saccades allows the visual system to work in an efficient manner whereby saccades move the eyes, placing the text onto the fovea (containing the highest percentage of cone cells), allowing for visual acuity to be at its peak in this region (Drieghe, 2011; Pijnacker et al., 2011).

In individuals diagnosed with AMD, the macula and fovea are damaged resulting in a decline of visual acuity and central vision loss (CVL). In the case of reading English, the majority of saccades (around 85%) happen from left-to-right (i.e., forward) (Liversedge and Findlay, 2000). However, around 10-15% of saccades are made backwards (regressions); from right to left, to read words which were missed or review text depending on the difficulty of the text. The majority of regressions are for the most part only a couple of letters long within a fixated word and may be as a result of the reader making a longer saccade which consequently would require the reader to make a short saccade to the left for reading to continue competently (Rayner, 1998). Another reason why short regressive saccades may occur are due to issues of processing the word that is currently being fixated. Longer regressions; 10 or more letter spaces are as a result of the reader not comprehending the text in which case good readers tend to accurately focus their eyes to the text that caused issues whereas poor readers tend to engage with the text more backwards to locate the text that caused them issues (Kennedy & Murray, 1987). Return sweeps are made to move gaze to the beginning of a new line. Typically, readers tend to underestimate the beginning of the new line and make small corrective movements to the left. As a consequence, a corrective saccade often occurs following the return sweep usually around 5-7 letter spaces from the ends of a line.

Figure 7

a) Diagram displaying the frequency distribution of fixation duration (in milliseconds) and b) the frequency distribution of forward saccade lengths (in character spaces) (Findlay & Gilchrist, 2003, p.87).



The typical fixation duration when reading English text typically lasts approximately 200-250ms (see Figure 7a) and the average saccade size is 7-9 letter spaces (see Figure 7b). Although most words during reading are fixated upon, there are some words which will be skipped or missed because foveal processing is not needed to identify that particular word. Around 85% of the time readers commonly fixate on content words which tend to be longer words and dismiss function words which are fixated upon around 35% of the time (such as: a, it, and, but) which tend to be much shorter in length. There is a clear association between the chance of fixating on a word and the length of that word; the longer the word length the higher the chance of fixating on that word (McConkie & Rayner, 1976; Rayner, 1998). For instance, words comprising of 2-3 letters are fixated upon around 25% of the time, on the other hand, words comprising of 8 letters or more are, for the majority of time, always fixated upon once or even multiple times (McConkie & Rayner, 1976). It is observed that readers fixate more on the beginning and the centre of the word. However, it has also been suggested that readers tend to fixate on the informative sections of words (optimal viewing position) (Liversedge and Findlay, 2000). Two terms are important when discussing character length (number of characters in a fixation) and fixations: visual span defined as the total number of characters determined by an individual during a fixation and the perceptual span, this is asymmetrical about the point of fixation, lengthening towards the direction at which the individual continues with the text. English readers typically have a perceptual span ranging from four characters (left of fixation) and 15 characters (right of fixation). The average duration, saccade length and the frequency of regressions vary among readers, where for a single passage of text the fixation duration amongst readers vary from under 100ms to over 500ms and the saccades range from 1 to 15 or more letter spaces (see Figure 7). Additionally, eye movements are largely affected by the textual and typographical factors. For instance, if text is conceptually more challenging, there is an increase in the length of time of fixation, a decrease in the length of saccade and an increase in the proportion of regressions made. Another factor is the quality of the print such as font used, the length of the line, and letter spacing which can all affect eye movements, if the text appears normal such typographical factors have minimal effects on eye movements (Rayner, 1998).

McConkie and Rayner (1975) investigated how much useful information was attained during periods of fixation using 'gaze-contingent' display techniques (see Figure 8). These include the moving window technique whereby the text is altered except in a specific region or window (predefined by the experimenter) around the point of fixation. This technique assumes that when the window is as big as the area from which the subject can gather information, there is a null effect between reading in that scenario and when there is no window. The window may be predefined as letter spaces or modified by the window so that it fits within the word boundaries. If the reader looks within the window region the text is clearly visible however, looking outside of this region results in the text being altered in some way. Although the reader may look where they wish to process the text the amount of useful information that is presented per fixation is under the control of the experimenter. The moving mask technique is similar to the moving window however here, the subject fixates whilst the mask alters the text around the point of fixation and the normal text is displayed beyond the mask area. A further technique called the boundary paradigm involves a single critical target word which is replaced by a different word, or non-word, as the readers' gaze crosses a pre-defined 'boundary' region. This technique assumes that inconsistences between the first initial word before the boundary region and what was processed after the boundary region with the second word, is attributed in the fixation time on the target word.

Figure 8

The first line shows a normal line of text. The second and third line displays an example of a moving window paradigm. The fourth and fifth line represent a foveal mask technique and the last two lines represent the invisible boundary technique. On each line the asterisk represents the point of fixation (Rayner, 1998).

```
the most important skill that humans          Normal
            *
-----------------------------------------
XXX Xost important sXXXX XXXX XXXXXX
            *                                 Moving
                                              Window

XXX XXXX XXXXXtant skill that XXXXXX
                      *
-----------------------------------------
the most XXXXXXXant skill that humans
            *
the most imporXXXXXXXkill that humans         Foveal Mask
                  *
-----------------------------------------
the most important money that humans
     *       *                                Boundary
the most important skill that humans
                      *
-----------------------------------------
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The properties of the normal human eye are the reason for the pattern of eye movements executed in different tasks that have the common feature of directing the fovea onto the stimulus requiring detailed attentional processing. The fixation-saccade repertoire is critically important in the process of reading and the eyes are controlled by moment-to-moment perceptual, cognitive and linguistic factors. In cases of eye disease, where vision is impaired, there are consequences for perceptual and cognitive processes that cannot be resolved by the oculomotor system. One example is macular degeneration, a condition most typically observed in older adults which can have dramatic, negative consequences for all visual tasks especially reading.

Age-Related Macular Degeneration

Age-related macular degeneration (AMD) is one of the leading causes of visual blindness in the world for older adults. It is a common retinal, progressive and degenerative disease of the ageing eye (a chronic disease of the macula) (Cheung & Eaton, 2013) and is the most common form of macular degeneration (Kolb, 1995). Due to the increasing ageing population worldwide, the number of AMD patients will rise to approximately 196 million in 2020 and it is estimated the number of patients will increase to 288 million in 2040 (Deng et al., 2021). AMD occurs in numerous stages from early, intermediate and advanced stages (see Figure 9). The first common signs often include deposits in the retina called drusen (insoluble extracellular aggregates) building in the retina (see Figure 9b). This tends to progress into developing abnormalities in the retina (Waugh et al., 2018).

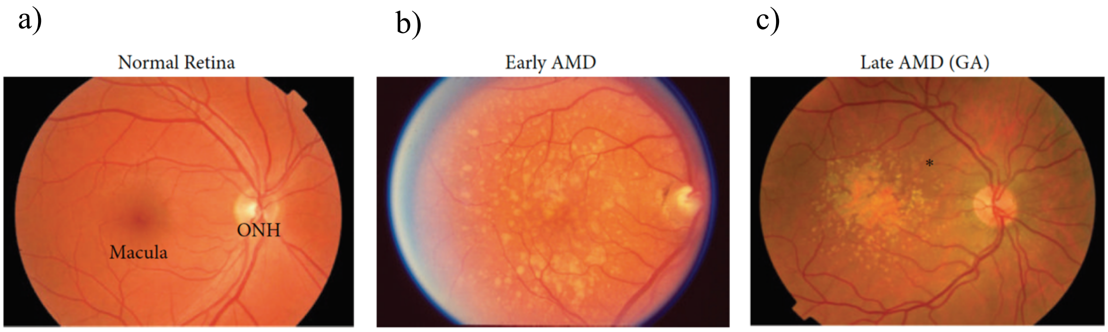
The presence of drusen, observed as yellow deposits present in the layers of the macula, specifically between the RPE and Bruch's membrane are the earliest signs of AMD. The size of the drusen can be divided into three categories; small when the drusen diameter is less than 63 micrometres (µm), intermediate when the drusen diameter is between 63 - 124µm and large if the drusen is greater than 124µm. The size and location of drusen, and pigment irregularity for the first eye and its effect on the other eye determines the classification system of AMD. The National Institutes of Health (NIH) Sponsored Age-Related Eye Disease Study (AREDS) categorised macular disease into five distinct categories. Category one refers to no drusen or neo-extensive small drusen present in the right and left eye, however no clinical signs of AMD present. Category two (early form of AMD) involves having considerable small amounts of drusen, non-extensive intermediate drusen or pigment irregularities in either the right or left eye.

Category three (intermediate form of AMD) refers to a substantial amount of drusen, extensive intermediate drusen or geographic atrophy not in the centre in at least one eye. Category four (advanced / late form of AMD) is specified as geographic atrophy where the visual acuity is characterised as below 20/32 as a result of damage of the nonadvanced AMD, for instance, increased drusen present in the fovea in either the right or left eye. Finally, category five (advanced / late form of AMD) is characterised as neovascular AMD (Cheung & Eaton, 2013).

The advanced stages of AMD occur in two forms: dry AMD and wet AMD, both resulting in a loss of vision. Advanced dry AMD is a chronic disease leading to a degree of visual loss and for some leading to severe visual blindness (Ambati & Fowler, 2012). Dry AMD is characterised by atrophy of the retina, with loss of areas or patches (referred to as geographic atrophy) of the retina resulting in a corresponding perceptual loss of the areas of the visual field received by the cells in these regions. Typically, the area of impaired vision is the highly detailed central vision, while the peripheral vision may be relatively preserved. This makes visual tasks such as recognising faces, reading and driving extremely challenging (Waugh et al., 2018). Geographic atrophy (late stage of dry AMD, see Figure 9c) is determined as dispersed or merging regions of deterioration of RPE cells and the light detecting retinal photoreceptors that depend on the RPE cells for trophic support. Typically, geographic atrophy affects the macula area, leaving the peripheral retina intact (Ambati & Fowler, 2012).

Figure 9

Stages of macular degeneration a) Normal and healthy retina, b) Early stage of dry Macular Degeneration and c) Wet age-related macular degeneration (advanced stage, Geographic Atrophy) (J. Gao et al., 2015).



Patients are often initially diagnosed with the dry form, but for one out of ten patients this can progress to the more severe wet form (Cheung & Eaton, 2013). Wet macular degeneration (also named exudative AMD) affects 10-15% of AMD patients and occurs suddenly and rapidly develops into severe visual loss if untreated (Ambati & Fowler, 2012). Wet AMD (see Figure 9c and 10) is determined by the growth of newly immature abnormal blood vessels to the outer retina, also referred to as choroidal neovascularisation and retinal angiomatous proliferation, which primarily affects the macula (Waugh et al., 2018). These abnormal blood vessels typically leak fluid below or under the retina causing it to lift. If this is left untreated severe blindness can occur and scarring can develop within several months (Ambati & Fowler, 2012). Although neovascular AMD is responsible for only 10-15% of cases diagnosed with AMD, it results in 80% of the cases being categorised as severe visual loss and blindness (with a visual acuity of 20/200 or worse) (Cheung & Eaton, 2013).

Although the age-related forms of macular degeneration are the most common, there are forms of juvenile macular dystrophy such as Stargardt disease. Stargardt's disease usually presents between 10 – 20 years of age, although this is not always the case and the disease may start at a later stage of life. The disease itself is inherited specifically damaging the macula, therefore, damaging the centre of the vision resulting in a lack of perceived detail. The peripheral vision commonly remains intact, although the disease can also affect the peripheral retina. Individuals with Stargardt's disease may start noticing blurriness, distortion and misty vision and problems with colour vision. Depending on the length of time the individual has acquired the disease, blind spots known as scotomas can appear in the centre of the vision (Allikmets et al., 1997).

Vitelliform macular dystrophy, or Best's disease, is also a genetically inherited condition which typically affects vision later in life, although it initially starts with alterations at the back of the eye between the ages of 3 and 15 years old. The disease usually affects both eyes however, the extent of damage may vary for each eye or the damage may occur monocularly. Best's disease affects and damages the macula, again causing major problems with central vision, affecting daily tasks such as reading, recognising faces and watching television. Similar to Stargardt's disease, Best's disease causes symptoms such as blurriness, distortions and over time leads to the occurrence of blind spots, leaving the periphery intact (Allikmets et al., 1999).

Sorsby's fundus dystrophy, another inherited disease in an autosomal dominant fashion affecting 1 in 220,000, usually occurring in later stages of life. The disease itself typically affects both men and women equally and has similar symptoms to the other forms of macular degeneration. The disease causes an aggregation of protein or lipid deposits under the retinal epithelial cells, called drusen. This results in alterations in a gene found in drusen-like deposits, this gene is a tissue inhibitor of metalloproteinases-3 (TIMP3) (Christensen et al., 2017).

Figure 10

Representation of how a scene with normal healthy vision (displayed on the left) looks compared with early macular degeneration (image in the middle) and late macular degeneration (on the right) (LaserEyeSurgeryHub, 2020).

Figure 10 displays a schematic representation of macular degeneration, although it is important to note that this image is used for educational purposes rather than an actual realistic view of what vision is like for those with macular degeneration, as most people diagnosed with AMD do not perceive their scotomas (Fletcher et al., 2012) . Taylor et al., (2018) reported that participants diagnosed with macular degeneration used words such as "blurry", "I see two chimney's instead of one", "can look like a wavy line", "foggy", "wobbly", "bending", "part of it missing" and "shimmering" to describe their vision (Taylor et al., 2018).

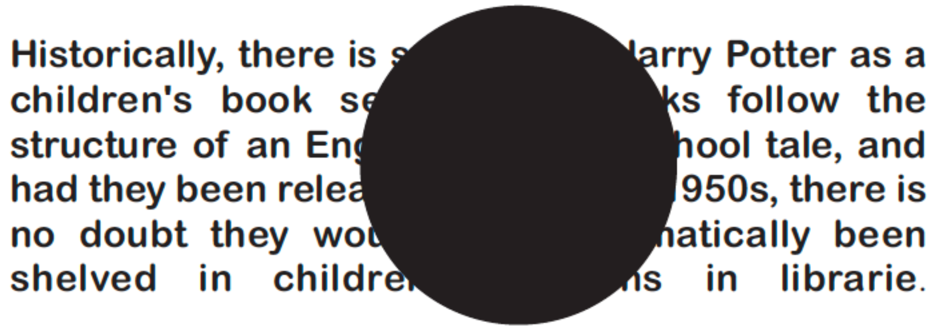
The underlying cause of macular degeneration is currently unknown; but it is correlated with risk factors such as age, gender, smoking, having high blood pressure, having a family history of macular degeneration, being overweight, hypertension, increased intake of fat, low dietary consumption of antioxidants and zinc and the amount of exposure to sunlight (Cheung & Eaton, 2013). Currently, there are no treatments available for dry AMD however, measures to prevent dry AMD such as quitting smoking, having a healthy diet and a consumption of antioxidants are recommended to patients with the disease and are currently the only available option (Cheung & Eaton, 2013). For wet AMD, there are drugs available called anti vascular endothelial growth factor (VEGF) which inhibit the compound VEGF. These drugs include Bevacizumab, Ranibizumab and Aflibercept which are known to stabilise vision for a length of time which varies patient to patient (Waugh et al., 2018). Ranibizumab (Lucentis) is a widely used treatment and recommended as a standard form of care in routine clinical practice (Johnston et al., 2017). This form of treatment (in the form of an injection in the eye) aims to block formation of abnormal blood vessels and prevent them from leaking, damaging and scarring the macula. Ranibizumab treatment is known as an intravitreal anti-vascular endothelial growth factor (anti-VEGF) agent which has shown to improve the visual acuity by an average of 7-11 letters over a year with monthly doses (Chong, 2016). Additionally, approximately 40% of patients acquired an additional 15 letters during the first year of undergoing Ranibizumab dosages, these improvements in vision were sustained at the follow-up period at 24 months. However, these treatments commonly aim to stabilise, maintain and improve vision acuity for a certain period of time (Eggers, 1961) rather than to cure vision and a few patients lost vision when undergoing this treatment (Chong, 2016).

Consequences of Macular Disease

For individuals diagnosed with macular disease with a resulting central vision loss (CVL), reading is a particular challenge (see Figure 11) (Ergun et al., 2003). Reading was reported to be the number one issue faced by these individuals (Hazel et al., 2000). Both forms of AMD (dry and wet) lead to a loss of central vision differing in size and location for example, loss of complete central vision may occur and this may be absolute or be scattered in other areas of vision (Ergun et al., 2003; Nazemi et al., 2005; Sunness et al., 1985). This loss of central vision results in individuals being unable to see in high detail and spatial resolution because of the high acuity centre of the retina being damaged (see Figure 11). The lesion or absence of this area of the retina results in the typical pattern of oculomotor movements adopted to read being ineffective leading to an inconsistent pattern of saccades in an attempt to continue to foveate words which has further been suggested as a factor for the decreased reading speed observed in this population (Crossland et al., 2004).

Figure 11

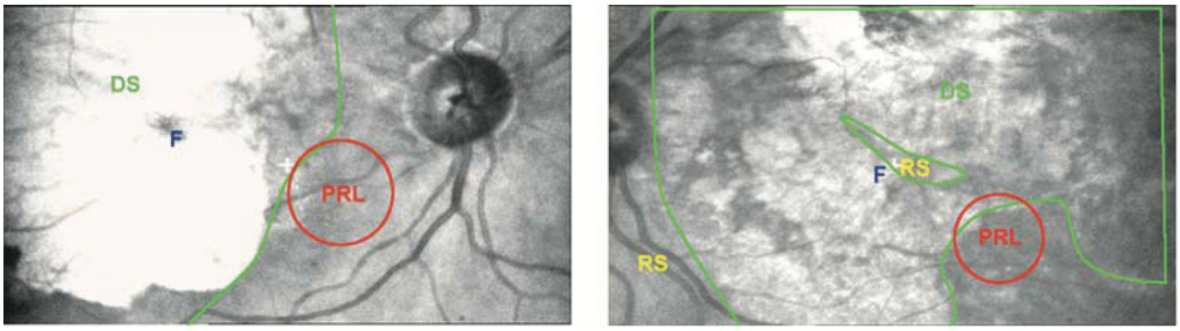
Representation of reading with a central scotoma acquired from age-related macular degeneration (Scherlen & Gautier, 2005).



In order to compensate for the loss of central vision, people with AMD may adopt a preferred retinal locus (PRL) for fixation. This involves shifting their vision slightly from the damaged area of the macula to a peripheral retinal location (Cheung & Legge, 2005). This preserved area of the retina acts as a *pseudo-fov*ea by restoring functions of the damaged macula therefore, maximising visual ability as well as being an advantage for a functional adaptation purpose with the goal of decreasing the influence of the scotoma on central visual fields (see Figure 12) (Barraza-Bernal et al., 2017; Markowitz & Aleykina, 2010). The adoption of a PRL, which can occur naturally without guidance, or training, differs among individuals depending on where the scotoma or damage to the macula has occurred (Gaffney et al., 2014). Individuals can also adopt different PRL's for different tasks (Crossland et al., 2005; Rubin & Feely, 2009; Timberlake et al., 1987). Commonly, the PRL is located near the edge of the central scotoma allowing for more complex tasks to be carried out such as pursuit and reading (Fletcher and Schuch, 1997). Additionally, Deruaz et al., (2004) suggested that the erratic eye movement behaviour observed in individuals with AMD may be purposefully produced with the saccades occurring regularly in between numerous PRLs to counter the effect of Troxler fading. This is where a stimulus in the periphery disappears from awareness due to adaptation and is only restored if there is a movement of the eye or scene, alternating the pattern of light on the retina (Clarke, 1960). Previous studies have demonstrated perceptual learning (defined as; “any relatively permanent and consistent change in the perception of a stimulus array, after practice or experience with this array”) (Chung, 2011, p.1164), or training to be beneficial for reading with central vision loss (peripheral reading) (Chung, 2011; Yu et al., 2010).

Figure 12

Left image displaying the features of a preferred retinal loci (PRLs) and scotoma (of right eye) and left image showing a patient with wet age-related macular degeneration. The green line represents the border of the scotoma, the yellow letters represent the region of the relative scotoma (RS), the red circles show the edges of the PRL and the blue (F) shows the best estimate of the region of the ineffectual fovea (Schuchard, 2005).



The majority of people diagnosed with eye disease (such as macular degeneration, glaucoma, cataracts etc.) are categorised as having low vision, with the largest number of patients with low vision caused by macular degeneration. Low vision is defined by the World Health Organisation as, “visual acuity of less than 6/18 but equal to or better than 3/60, or a corresponding visual field loss to less than 20°, in the better eye with the best possible correction. ‘Blindness’ is defined as visual acuity of less than 3/60, or a corresponding visual field loss to less than 10°, in the better eye with the best possible correction. ‘Visual impairment’ includes both low vision and blindness” (Pararajasegaram, 1998, p.8). Low vision rehabilitation aims to enhance the implementation of residual vision after severe vision loss and help train and teach the reader skills to help improve visual functioning in daily life. Additionally, low vision rehabilitation aims to facilitate people to adapt to their loss of vision and aid psychosocial functioning. All of these skills help to encourage independence and active participation in society and ultimately enhance quality of life for people who have a visual impairment (van Nispen et al., 2020).

A loss of central vision has severe consequences on the individuals’ ability to read. This has a detrimental effect on the quality of life for individuals diagnosed with macular degeneration (Fine et al., 1999), and the aim to re-establish reading has prompted numerous therapeutic approaches such as eccentric viewing and steady eye strategy (Cheung, Sing-Hang and Legge, 2005). Eccentric Viewing consists of making fixations away from the object of interest, thus adopting a PRL to extract the desired visual information by functionally substituting the fovea (Timberlake, Peli, Essock, & Augliere, 1987). Eccentric viewing training involves helping a person to adopt their PRL to view an object, thus aiming to improve fixation stability. Improving fixation stability is considered to improve reading performance, and further helping individuals to adopt a more functional PRL (Palmer, Logan, Nabili, and Dutton, 2009). Nilsson et al., (2003) found that 18 out of 20 patients diagnosed with neovascular AMD with CVL and an average best corrected visual acuity (BCVA) of 20/475, learned to adopt eccentric viewing. In addition to this, when training was provided (mean time of 5.2 hours) there was a significant improvement in reading rate (from approximately 9.0 ± 5.8 words per minute (wpm) to 68.3 ± 19.4 wpm). It was also reported that the effects of low vision techniques on reading rate (wpm) compared with microperimetry biofeedback and microscopes teaching program, the eccentric viewing training showed to have the highest increase in reading rate (Hamade et al., 2016).

The Steady-eye strategy can be used in addition to eccentric viewing and is primarily used for reading. This requires the patient to fixate at a region on a page and then move the text from right-to-left, thus enabling the person to read without making saccades (Watson & Berg, 1983). The goal of steady eye strategy is to eliminate the need for forward saccades and to improve the effectiveness of reading with a PRL (Gaffney, Margrain, Brunce, Binns, 2014). Steady-eye strategy should reduce gaze instability, which is a common problem for individuals with central field loss when reading normal static form text (Crossland, Culham and Rubin, 2004). In practice reading with the eccentric-viewing and steady-eye strategies is difficult as a result of poor visual acuity and the disruption of typical eye movement behaviour. The natural tendency to direct gaze onto the word of interest consequently leads to the eyes being directed onto the text thus working against the eccentric viewing strategy.

Scrolling text and reading with healthy eye movements

The demands for reading with horizontally scrolling text are adapted from the normal, typical reading behaviour. This is because the movement of the horizontally scrolling text means that the oculomotor system must regard a supplementary dimension in planning saccades which may affect the online deployment of attention resulting in possible implications for cognitive processing (Kornrumpf et al., 2016). Previous research has suggested consistently that scrolling text is read by a variation of smooth-pursuit and saccadic eye movements. Additional detailed investigations have demonstrated multiple interactions between smooth pursuit and saccades. Valsecchi et al., (2013) found that the employment of smooth pursuit was increased after the implementation of a saccade. However, the peak velocity of saccades was decreased for horizontally scrolling text in which both the saccades and the pursuit were implemented in opposing directions. Valsecchi et al., (2013) also demonstrated that some findings of reading with static text broaden to scrolling text (or also referred to as drifting text), these include preferred viewing location, the inverted optimal viewing position and the association between saccade amplitude and subsequent pursuit or fixation duration. It was concluded that overall, individual eye movement parameters which include saccade amplitude and fixation and/or pursuit durations were associated across self-paced reading of static text and time limited reading of static and scrolling text. It was further concluded that such basic findings from oculomotor research are also applicable to reading with scrolling text. This demonstrates that reading with scrolling text as a visuomotor behaviour that is determined by low-level eye movement control as well as by the cognitive and linguistic processing (Valsecchi et al., 2013).

It must be noted that with scrolling text, processing of the text may be impacted by how well the eye is able to implement a stable fixation on the text. On the other hand, with static text, the ability to sustain stability of the retinal image of a fixated word is straightforward, unlike scrolling text, where it is necessary for cautious matching of the eye velocity to the movement of the stimulus. However, this is possible after a particular period of familiarisation to the stimulus movement when the stimuli are displayed at a fixed velocity (Lovejoy et al., 2009). In cases where the eyes are moving in smooth pursuit in line with the text itself, this will encourage the word under fixation to continue to be under stable foveal inspection. In cases where the eyes are moving slower than the text then the character which is first foveated will shift out of the foveal vision in a leftward direction and following characters in the word being presented and potentially another could come under central fixation. In contrast, if the eyes move faster than the text then the converse scenario will happen and letters which are presented earlier in the word will move into central foveal vision (Harvey et al., 2017). It must be noted that reading with scrolling text has potential disadvantages such as the inability to reinspect text as well as increased challenges in spatially mapping the text to make regressive saccades. Despite this, there are numerous advantages of reading with scrolling text such as improved peripheral acuity thus enhancing visual functioning and reducing the demands on the eye movement system potentially improving the readers ability to maintain reading strategies.

Dynamic text and reading with a central vision loss

It has been suggested that a reduction of reading speed with individuals who are visually impaired may be a consequence of inadequate eye-movement control. With normal readers with no visual or cognitive impairments, reading static text typically involves making eye movements that move in a saccadic fashion, approximately once every 250ms (Rayner, 1978). The use of digital displays enables text to be presented in different ways including dynamically, for example, as a single line of text that scrolls (horizontally) smoothly from right-to-left like a news ticker. The scrolling text presentation, also termed Times Square format, or drifting text is commonly encountered on LED announcement boards. The use of scrolling text is of interest as it enables text to be displayed in compact spaces such as mobile phones and watches. Previous research investigating scrolling text has also demonstrated its potential as a reading aiding for those with visual impairments such as CVL (Bowers et al., 2004; Calabrèse et al., 2014; Harland et al., 1998; Harvey & Walker, 2014; Legge, Ross, Maxwell, et al., 1989; Walker, 2013; Walker et al., 2016). In comparison to reading normal text, which places high demands on the oculomotor system, the demands of reading with scrolling text are potentially reduced as the text moves across the screen and retina. Scrolling text has been investigated as a reading aid for people with macular degeneration due to the ability of supporting reading strategies (i.e. eccentric viewing and steady eye strategy), by decreasing the need to make eye movements (Calabrèse et al., 2014). Scrolling text also preserves the parafoveal preview effect for the partial pre-processing of upcoming words outside of the fovea (parafovea), which is crucial for reading fluently (Schotter, Angele, & Rayner, 2012; White, Warren, & Reichle, 2011).

Another form of dynamic text presentation, that has been of particular theoretical interest, is rapid serial visual presentation or RSVP (Rubin & Turano, 1992, 1994). RSVP is where one word is presented in sequential order one after the other in the centre of a screen. RSVP may be suboptimal as a reading aid because of the elimination of parafoveal preview. Previous research comparing these two dynamic formats, RSVP and scrolling text presentation, have shown that scrolling text results in better reading comprehension (Kang & Muter, 1989) and a better memory for the material, which is sustained at a higher reading speed. Furthermore, there has been a much higher subjective preference for reading with scrolling text compared to RSVP (Bowers et al., 2004; Harland et al., 1998; Shieh et al., 2005; Walker, 2013; Walker et al., 2016). Both forms of dynamic text (scrolling text and RSVP) have been proposed as reading methods for people with CVL. In order to examine reading, past research (e.g., Aquilante et al., 2001; Bernard et al., 2007; Bowers et al., 2004; Buettner et al., 1985; Fine & Peli, 1995; Harvey, Anderson &

Walker, 2019; Harvey & Walker, 2014; Legge, Ross, Maxwell, et al., 1989; Öquist & Lundin, 2007; Rubin & Turano, 1994, 1992; Walker et al., 2016) have primarily focused on measures such as reading speed, reading accuracy and reading comprehension which may be interconnected.

One method for investigating reading in low vision has been to measure the reading speed that can be attained by individuals with dynamic formats (Harland et al., 1998; Legge, Ross, Maxwell, et al., 1989; Rubin & Turano, 1994). Reading speed is a useful psychophysical measure however, a potential issue for dynamic text formats is that reading speed depends on the rate of text presentation, which imposes a particular maximum reading speed (Slattery & Rayner, 2010). Scrolling text presented at higher speeds can for example lead to perceptual blurring and the pattern of optokinetic nystagmus-like eye movements used to read scrolling text breaks down (Buettner et al., 1985; Harvey & Walker, 2014; Kaminiarz et al., 2010). Furthermore, reading speed does not provide evidence of whether the individual has understood and comprehended the text. A direct assessment of reading comprehension is therefore a richer measure of reading performance. It is also important to consider elicited sequential presentation, which is a variant of RSVP method for low vision reading. In both RSVP and elicited sequential presentation, the words are presented in sequential order in the same location of the display screen. However, with elicited sequential presentation, the reader elicits the presentation of the word by a button press, however, with RSVP the word is automatically presented at a fixed interval. Research which compared reading rates RSVP, elicited sequential presentation, and conventional closed-circuit television (CCTV) reading aid demonstrated that for a total of 15 slow readers, elicited sequential presentation was better than RSVP and produces reading speeds which average 47% faster than RSVP. It was concluded that slower readers benefit more than faster readers (Arditi, 1999).

Laboratory studies using an *artificial scotoma paradigm* have been widely used to simulate visual deficits using an eye-tracker and in carefully controlled experimental conditions (e.g. Cornelissen et al., 2005; Janssen & Verghese, 2015; Lingnau et al., 2008). Primarily the use of an artificial scotoma paradigm has focused on fovea centred artificial scotomas to comprehend how patients diagnosed with low vision, or central scotomas (for example, as a result of macular degeneration) learn to implement a pseudofovea (using a PRL) and the implementation of reading strategies such as eccentric viewing and steady eye strategies with text displays (Harvey & Walker, 2014). Although, it should be noted that the simulation itself uses a pre-defined estimate of a scotoma whereas for individuals with central scotomas or CVL, the scotoma may take on a variety of forms including having multiple scotomas. Therefore, an artificial scotoma is not a complete representation of the disease itself. Additionally, another limitation of an artificial scotoma are the differences between using an artificial scotoma in an experiment for a few hours compared with a real scotoma for months or years. Nevertheless, the use of an artificial scotoma paradigm is important and useful to allow for stringent testing under laboratory conditions (Harvey, Anderson and Walker, 2019).

Rubin & Turano (1992) examined reading performance with RSVP (eliminating the need to make saccades, thus making better use of the PRL) and static text in participants with low vision. The participants showed an increase of reading rate, a reduction of saccades and a further reduction in word duration (successive words displayed for a fixed length of duration) compared to the static text (Rubin & Turano, 1992). However, there was less improvement in reading for participants with central scotomas compared to the participants with low vision without a central field loss. On average participants with normal vision required roughly 200ms per word for reading the static text and only 50ms per word when reading with the RSVP format. This may be explained by saccades not being required when reading with RSVP (Rubin & Turano, 1992), but the consequences for comprehension are unclear. Addition to this, further research by Aquilante et al., (2001) examined word duration with RSVP in three groups of participants; normally sighted younger and elder participants and individuals with CVL as a result of age-related maculopathy. The text was presented at a constant rate and at three speeds where word presentation duration differed depending on word length. Findings showed that when word duration was presented at a constant rate the elder participants (reading with central vision) read the fastest. On the other hand, the younger participants who read random words peripherally read faster at a differing word duration rate. The participants with CVL read 33% faster when the speed of the words being presented varied with word length. The results also showed a trend where slow readers with CVL demonstrated to benefit more compared to the fast readers with CVL. It was concluded that changing the word duration in accordance with word length when presenting text as RSVP, reading speed is enhanced for patients with low vision with a loss of central vision.

However, a potential limiting factor when reading with peripheral vision using eccentric viewing is the effect of perceptual crowding. Crowding is the inability to distinguish targets in the presence of objects located too close together (Chung, 2004). The critical distance between objects increases with increasing eccentricity of the target therefore, simply enlarging text in the case of reading with the peripheral vision is not enough (Bouma, 1970; Whitney & Levi, 2011). Instead, other characteristics of the text such as spacing of words or spaces in-between lines of text (paragraph format) may be necessary to enhance reading. This is supported by a study which showed an overall improved reading performance with static text with increased word and line spacing in a sample of individuals with macular disease with CVL (Blackmore-Wright et al., 2013). Additionally, when examining crowding at the word level and the impact of word spacing on reading rate in both the central and peripheral vision (using RSVP), it was found that reading rates are increased for un-flanked conditions than for the conditions that were flanked in relation to RSVP which is typically single-word presentation. Secondly, it was demonstrated that crowding was present between adjacent words. The comparison of the effects of crowding with the central and peripheral vision showed that the spatial properties of word crowding is increased at eccentricities of 5° and 10° (thus further out into the periphery) compared to the effect observed at the fovea (central vision). It was also found that in both the peripheral and central vision, reading rate increased with vertical word spacing. This improvement was better in the periphery compared to the central vision (Chung, 2004). Other studies have however disputed this claim (e.g. Bernard et al., 2008) suggesting that there are other factors influencing reading performance more than spacing. For instance, reading performance (reading rate and accuracy) when reading with multiline paragraph format with interline spacing was investigated. This was done using a gaze-contingent display paradigm to simulate an artificial central scotoma with individuals who were normally sighted. It was found that perceptual learning (Chung, 2011), print size and scotoma size all had a strong influence over reading performance however, interline spacing had a small effect whereby a small increase in reading performance was seen after a large increase in spacing. This contrasts with Chung's (2004) findings, although it is important to note the difference of text displays used (RSVP vs PAGE). It was suggested that the inconsistency of these findings may be a result of vertical crowding decreasing when reading sentences that are meaningful or the reliance of variables such as attention and visuomotor control differing or varying with the text display type which affects reading rate (Bernard & Scherlen, 2007).

A loss of central vision results in decreased reading rates compared with individuals who have normal vision. This low reading rate is usually below 100 wpm for individuals with low vision, this can decrease to as slow as 50 wpm, and in some severe cases can be as low as 10 or 20 wpm (Legge, Ross, Maxwell and Luebker, 1989). Reading comprehension for those with low vision (as a result of eye diseases such as congenital cataract, optic atrophy, albinism, macular degeneration etc.) often indicates no decline in comprehension when scrolling text rate is lower than 100 wpm (Legge, Ross, Maxwell and Luebker, 1989). Legge and colleagues (1989) found that the comprehension rates tended to fall at an average scrolling rate of 230 wpm to 320 wpm. In a further study comparing horizontally scrolling text and static text, findings revealed that the ability to comprehend scrolling text can be achieved at an equal rate to the natural reading speed (i.e., at normal reading level). Thus, these findings are encouraging for individuals who are visually impaired as it emphasises that normal comprehension can be achieved at a decreased reading speed (Legge, Ross, Luebker, et al., 1989). Previous research has proposed scrolling text to be an effective method for reading with low vision for instance, Legge, Ross, Leubker and Lamay (1989) found that reading speed was faster by 15% with text presented as scrolling compared to static text with a low vision population (five of whom were diagnosed with macular degeneration). Additionally, if the text was moved sufficiently slowly, similar reading comprehension abilities to controls with normal sighted vision were observed. Thus, Legge et al., (1989) concluded that the results were regarded as being encouraging for individuals with low vision because they demonstrate that good comprehension is achievable at low reading speeds as the majority of participants (who varied in their pathologies) were nearly able to achieve normal comprehension.

Both RSVP and scrolling text displays involve a decreased number of eye movements in order to read the text, potentially leading to an increase in reading speed. For instance, Rubin and Turano (1994) investigated reading performance (specifically reading speed) by comparing RSVP text with static text with participants with low vision with central scotomas and participants with low vision without central scotomas. It was found that although reading rate increased for all participants with the RSVP text display, there was a decrease in improvement of reading with the RSVP text display with participants with low vision with a central field loss compared to participants with low vision without a central field loss. Rubin and Turano (1994) suggested that the faster reading speed observed with participants with low vision with central scotomas with RSVP as a result of making fewer saccadic eye movements. In the case of individuals with a loss of central vision, the execution of saccades tend to be atypical (Rubin and Turano, 1992) as well as making hypometric saccades (smaller than normal) to locate visual targets (White & Bedell, 1990; Whittaker et al., 1988). A study by McMahon, Hansen and Viana (1991), found that participants with CVL made a greater number of saccades (1.8 times more) than participants who were normally sighted, with a significant number of these saccades being regressive.

Bowers, Woods and Peli (2004) investigated the association between different PRL regions and reading speed in individuals with low vision and central field loss (in most cases) when reading with four different text displays: horizontally scrolling text, vertically scrolling text, RSVP and PAGE format (static text). This was to examine whether the use of horizontally scrolling text would be a greater help for patients with vertical PRLs (i.e., above or below the scotoma) and if text scrolling vertically would be more useful for those with lateral PRLs (i.e., right or left of the scotoma). This was done by measuring reading speed with different PRL locations with the four text displays. It was found that the PRL location and display had no effect on reading speed. However, more than half of the service-users with low-vision preferred reading with the horizontally scrolling format rather than RSVP. It was suggested that this may be due to making less oculomotor movements when reading horizontally scrolling text compared with static text. Additionally, it has been proposed that individuals who are visually impaired read 13% slower with the RSVP text display than the horizontally scrolling condition (Fine & Peli, 1995) and subjective ratings have shown that RSVP is a less well-liked format for reading (Bowers, Woods, & Peli, 2004; Harland, Legge, & Luebker, 1998).

The perceptual effect of crowding may need to be taken into account with scrolling text (Venkataraman et al., 2017). It has been shown that crowding is enhanced with smooth pursuit eye movements. When information is presented in the opposite direction to the pursuit (at approximately 3° eccentricity) the effects of crowding tend to increase in comparison to when information is presented in the same direction to the pursuit. Crowding has shown to be ineffective for objects that are located around 7° from the fovea. It was suggested that this effect may be associated to the distance at which the fovea is lagging whilst tracking or following the target during smooth oculomotor movements. Thus, visual perception is dynamically modulated depending on the planned location of oculomotor demands (Harrison et al., 2014). Taking this into account, it may be beneficial to include greater word spacing with scrolling text than for static text to overcome this effect. However, it is not clear how this will affect reading with the steady eye strategy and secondly, how much spacing in between words is needed for it to be beneficial or at what stage increased word spacing may be fruitless. A study with the implementation of a gaze-contingent artificial scotoma by Harvey, Anderson and Walker (2019) investigated whether modulating inter-word spacing to minimise the impacts of crowding is beneficial for reading performance with scrolling text. This was done using a scotoma of 8° in diameter and sentences were displayed with inter-word spacing of one, two and three characters. It was found that triple word spacing significantly aided reading accuracy and memory recall regardless of the speed of the scrolling text. Reading performance with scrolling text may be enhanced with greater inter-word spacing as a result of minimising the effects of visual crowding with a loss of central vision (Harvey, Anderson and Walker, 2019).

Furthermore, Kang and Mutar (1989) investigated reading comprehension with participants (students) who were normally sighted with text presented as horizontally scrolling text in three different ways; the first was a pixel scrolling text condition, where the text was moved within the viewing region by one pixel at a time to the left (used to give an appearance of a smooth, continuous movement of text). The second was letter scrolling text (moved by one letter to the left, shifted 11 pixels at a time) and finally the word scrolling text; word moved to the left depending on the width of the upcoming word on the left in the viewing window. A further novel condition used a modified RSVP format where several words were presented sequentially (average number of words in a window was 17). They found that the pixel scrolling text display and the letter scrolling text display resulted in as good comprehension as the RSVP text display. Additionally, they found that at a reading speed of around 194 wpm, there was no significant differences in reading comprehension between the scrolling text display and RSVP. Participants additionally reported a higher subjective user preference for the scrolling display compared to the RSVP text display consistent with the findings of Bowers et al., (2004).

An examination of both reading speed and comprehension in participants with normal vision, with text presented as scrolling, static and RSVP text on a mobile phone found that static text was read significantly faster than scrolling and RSVP text. It is important to note however, that the text was presented on a small screen size, thus although the finding suggests that static text was better in terms of reading speed for readers who were normally-sighted this may not be the case in people with low vision and CVL (Öquist & Lundin, 2007). Earlier research by Fine & Peli (1995) with subjects who were visually impaired and normally sighted investigated reading rates with text presented as RSVP and scrolling text. They found no difference of reading performance for readers with acuity worse than 20/50 in the better seeing eye. For participants with normal vision the elimination or need to make eye movements was observed to be beneficial when reading with RSVP. It was proposed that the continuous motion of scrolling text aids individuals with visual impairment by potentially decreasing the amount of eye movements necessary to read text. Previous research (Rubin & Turano, 1994) suggested that participants with CVL make intra-word saccades when reading RSVP text which take planning and time to implement. However, when reading with scrolling text, if it is unnecessary to plan saccades, theoretically reading with scrolling text would be faster than RSVP (Whittaker et al., 1993). However, it is important to note that the former study (Öquist & Lundin, 2007) used participants with normal vision using RSVP, scroll and PAGE text (paragraph, multiline text) on a mobile phone screen whereas the latter (Fine & Peli, 1995) used individuals with low-vision and the text was presented on a computer screen with RSVP and scrolling text. Additionally, it was proposed that readers with a loss of central vision may potentially benefit from entrainment of their eye movements when reading with scrolling text as this captures the motion of the eyes similar to an optokinetic nystagmus producing stimulus (Kowler, 1990; Legge, Pelli, et al., 1985) which may exclude some challenges in fixation stability especially when such patients are required to fixate on a single letter (McMahon et al., 1991), therefore saving additional time. Moreover, the steadiness of the eyes when fixated on a stimulus will further result in the image being visibly clearer leading to enhanced reading (Fine & Peli, 1995). In addition to this, there has been research to suggest that reading scrolling text may improve peripheral acuity (Venkataraman et al., 2017).

A variety of research has examined reading performance, by measuring reading speed. However, one issue with dynamic text is that the rate of presentation at which text is displayed will influence reading speed. With the scrolling format, perceptual blurring occurs at higher scrolling rates and the oculomotor fixation-saccade sequence starts to break down making direct comparisons with other methods such as RSVP difficult. Although reading speed is a useful psychophysical measure it is not the ultimate goal of reading. It is important therefore to include comprehension as a measure of reading success when studying dynamic text. In addition, the previous literature has often focused on samples with low vision, with a variety of eye pathologies and few have studied the effect of CVL only. Research on reading performance with dynamic text using participants with macular degeneration is limited. The advancement of technology means that reading aids such as using scrolling text which supports eccentric reading are much more accessible to people with visual impairments so this methodology can have a real-world impact.

Thesis Overview

This thesis describes an experimental investigation of reading performance with dynamic (scrolling and RSVP) and static text presentation with a central loss of vision (i.e., from macular degeneration). This was performed with a combination of laboratory-based experiments using a gaze contingent artificial scotoma paradigm to simulate CVL which will be replicated with individuals diagnosed with macular degeneration with CVL. The artificial scotoma paradigm allows for a longer testing period and multiple repeated trials under controlled conditions. Replicating the laboratory-based studies allows the possibility of generalising findings from laboratory-based work to individuals with CVL. To measure reading performance, reading comprehension and accuracy will be used primarily rather than reading speed as it is a less appropriate measure with dynamic text formats. The effect of perceptual learning (in this case defined as, training to be beneficial for reading with central vision loss) (Chung 2011; Yu et al., 2010)) for reading with eccentric viewing will be examined by including biofeedback when reading (to entrain the maintenance of the eccentric viewing location) with dynamic text with an artificial scotoma in the laboratory. This effect of perceptual learning was replicated with individuals with macular degeneration. For the participants with macular degeneration, additional qualitative measures (subjective user feedback through a questionnaire) evaluating the MD_evReader app (Walker, 2013) as a stand-alone app to practice eccentric reading and experience of reading with scrolling text were also obtained. Finally, to obtain a thorough feedback from users with low vision on their experience of reading with scrolling text, an on-line study was conducted.

The aims of this thesis are:

- To investigate reading performance with dynamic text formats (scrolling text and RSVP) when reading with a central vision loss in laboratory-based studies and in individuals with macular degeneration.

- To see if the results from laboratory-based studies of reading using artificial scotoma can be generalised to reading performance of individuals with actual central vision loss caused by macular degeneration.

- To investigate how well participants adhere to the eccentric viewing strategy with scrolling text compared to static text.

- To evaluate the effectiveness of training individuals and biofeedback to maintain effective reading strategies with dynamic scrolling text compared to static text in central vision loss.

- To evaluate the effectiveness of training individuals with central vision loss and macular degeneration to read scrolling text.

- To obtain feedback on the subjective experience of reading with scrolling text from individuals with macular degeneration.

Chapter 2.

Experiment 1a. Reading with a simulated scotoma with static and dynamic text displays.

Introduction

A major advantage of employing an artificial scotoma paradigm is that it allows for flexibility to test for rigorous, longer periods and to repeat testing in a laboratory-based environment under controlled conditions. This is particularly useful as testing for long periods is difficult with elder participants diagnosed with macular degeneration. Furthermore, it allows to see whether findings based on the laboratory-studies are generalisable to the real world. The laboratory-based study allows to fine-tune the experiment before applying and replicating it in the real world. Additionally, the implementation of an artificial scotoma allows researchers to understand real world visual defects with central field loss and to test under conditions that may not be possible with individuals who acquire the disease. Another advantage of adopting a simulated scotoma in individuals who are normally sighted is the ability to have control over the sizes and shapes of the scotoma in conjunction with adaptation period across participants who have no other visual impairment, thus excluding any confounds that may occur in the results (Bertera, 1988). Moreover, there is greater control over individual differences as the same participants can be tested in scotoma and no scotoma conditions. However, an artificial induced central field loss may not be directly comparable with an actual central field loss and the natural adaptations which occur with real central scotomas. For example, real scotomas may occur in many different shapes and sizes and in multiple forms, rather than just a singular artificial scotoma. Additionally, most individuals have acquired a central field loss in the real world for many years, where natural adaptations have occurred to help the individual use their vision as best as possible using various techniques.

This experiment will use an artificial scotoma paradigm with participants who are normally sighted to assess reading performance (comprehension and accuracy) with different text presentations (single-line static text, multiline paragraph format, horizontal line of scrolling text and RSVP text display). The aim is to test the hypothesis that reading performance (comprehension) will be better with scrolling text than RSVP and static text, as a result of being able to better maintain and employ reading strategies such as eccentric viewing with a loss of central vision. This experiment allows participants to manipulate the speed of the text presentation to a speed they feel comfortable reading during the scrolling text display and select a comfortable reading speed for the RSVP text display. The hypothesis of this experiment was that reading performance will be enhanced with scrolling text compared to all of the other text display types.

Method

Participants

19 students (18 female and 1 male) were recruited from Royal Holloway, University of London (mean (M) age = 19.78, standard deviation (SD) of age = 1.26). The participants self-reported normal or corrected to normal vision (best corrected binocular visual acuity of 0.0logMAR or better), had English as their first language, and had no language or reading deficits. All of the participants gave written informed consent prior to participating within the study. The study was self-certified in line with the

guidelines set by the College Ethics Committee at Royal Holloway, University of London (see Appendix 1).

Stimulus and Apparatus

Passages of text taken from the *'York Assessment of Reading for Comprehension (YARC): Passage Reading Secondary'* (Stothard, Hulme, Clarke, Barmby, & Snowling, 2010) were used as stimuli (see Appendix 5). The YARC is a standardised assessment (designed for 12-16 year olds) that assesses three aspects of reading: decoding (word reading), fluency (reading rate) and text comprehension (literal and inferential meaning). A modified protocol (comprehension battery) was used for this study as some questions required the participants to have the text in front of them in order to answer the questions. However, in this case the text was removed before the participants were given the comprehension questions (i.e., once reading the passage, participants could not revisit the text). The comprehension assessment also included a summary section, which allows to assess whether key points in the passage were comprehended (measuring gist comprehension). The summary section was scored independently and was scored out of 7-9 depending on the passage. The comprehension questions were presented in paper format and were given to participants immediately after each condition was completed. Participants had no time limit to complete the comprehension questions, however, typically took around 10-15 minutes to complete on average. Per session the length of time (approximately) to complete all aspects of the session was 1 hour. The questions examined literal and inference-based comprehension. Participants were asked to summarise the passage, with marks given for each correct key point noted from a predefined list. The full set of YARC comprehension questions for each passage have an unequal number of questions for each passage. After reducing the YARC comprehension questions, there were still an unequal number of questions and summary points that could be achieved for each passage (see Table 1). Scores were therefore analysed as percentages.

Table 1

The structure of the literal, inference and summary questions, the total number of points available for each passage. The total number of sentences and words within each passage are also displayed (Stothard et al., 2010).

Passage of text	Literal	Inference	Summary	Total available score	Total number of sentences
Food in the Medieval Times	7	3	7	17	20
The Schoolboy	5	6	9	20	26
Honey for you, Honey for me	7	4	11	22	24
Louise Nevelson – Art in a box	5	4	8	22	22

The stimuli were presented on a BenQ LED 27-inch monitor (1920x1080 pixels) running at 100 hertz (Hz) refresh rate. A viewing distance of 70 centimetres (cm) was maintained by a table mounted chin and head rest. The height of each character displayed was 2.5 cm. All of the sentences were displayed as white text (72point font size) in Courier New font on a black background (Legge, Ross, Maxwell & Luebker, 1989). A small lamp was used to adjust illumination within the room. The text was located on the screen at 960x540 pixels. The single-line static text (Figure 13a) and scrolling text (Figure 13b) was presented as a single line of text. The multiline paragraph format (Figure 13c) was presented as two lines, with double line and double word spacing to ensure consistency with previous research (Blackmore-Wright, Georgeson & Anderson, 2013). The participants were informed about the eccentric viewing strategy and instructed for all text displays (except multiline paragraph format) to keep their eyes above the text at the location of the guideline and try and read the text below whilst adhering to this strategy. For the single-line static text and scrolling text the guideline was presented as a grey horizontal line located 4° above the text (Figure 13a and 13b). For the RSVP text presentation, the guideline was presented as a cross 4° above the presented word (Figure 13d).

Artificial Scotoma (Gaze-contingent)

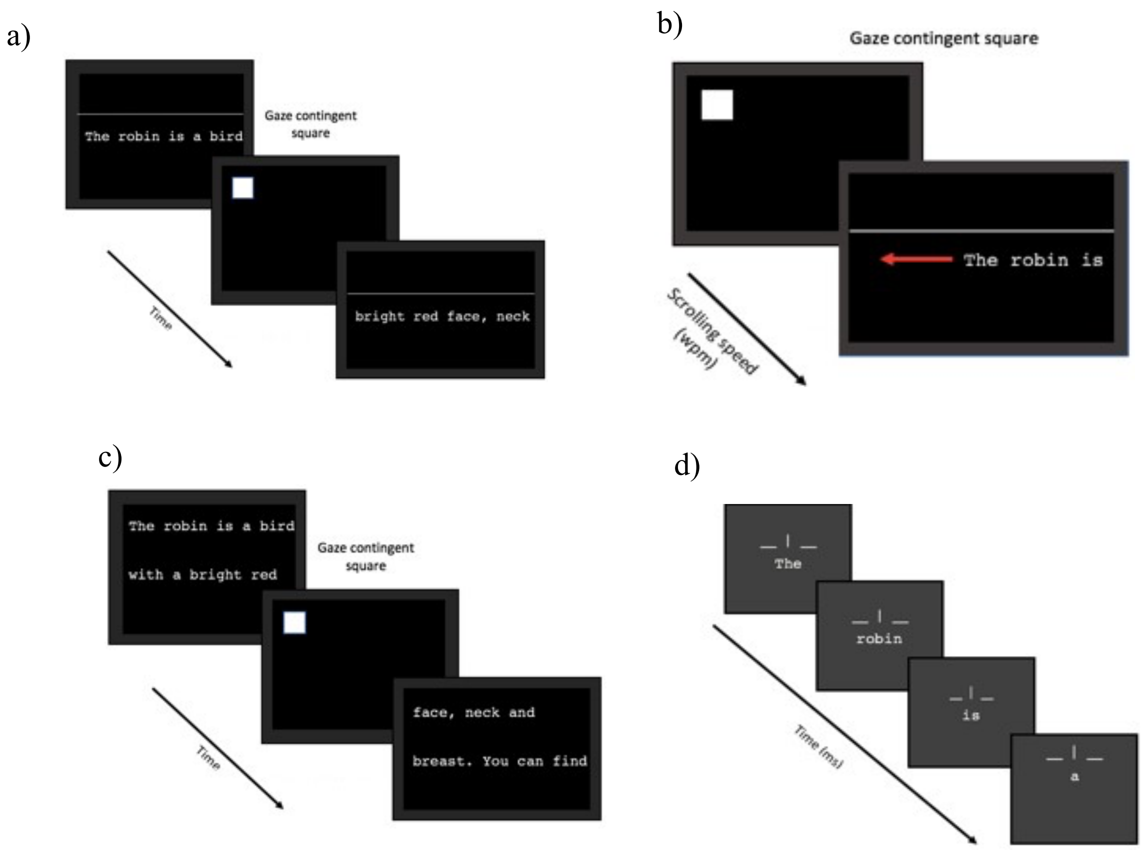
Eye movements were recorded monocularly, from the right eye (pupil and corneal reflection) with an SR Research (Ontario Ca) EyeLink 1000 eye tracker sampling at 1000 Hz. The eye tracker controlled a predefined gaze-contingent artificial circular scotoma of 8° diameter. The scotoma was identical to the background colour and luminance (black). A standard horizontal and vertical 9-point calibration routine was performed at the start of each session and a validation route was performed with the same 9-points to check spatial accuracy. The calibration was repeated if average fixation error was greater than 0.5°. Stimulus presentation and the gaze-contingent scotoma were controlled using Experiment Builder software (SR Research, Ontario Ca). Before each initial trial a required fixation location indicated with a white square was located 4° above the region of the text presentation. As a result, all participants started reading from the same eccentric fixation as this was required to initiate the trial for each text display. To ensure the gaze position was maintained a white gaze contingent square (0.8°) appeared in the same region and was used as the drift checking stimulus and required a minimum of 40 ms of fixation to initiate the trial allowing for a steady fixation. Eye position was used to present a scotoma that was based on the previous sample region every 10ms, however, this was disregarded if a blink was recognised in which case the scotoma was redrawn constantly in the same region until the blink was no longer recognised. The recognition of a blink began when the pupil size decreased 90% of the size of the three-sample moving mean of pupil size. As a result of this, individual pupil samples which were made following the decreased 90%, were collated with the most previous mean generated before the blink was recognised, this process continued until it no longer fitted this criterion in which case the scotoma was redrawn at a new sample region and a new three sample moving mean was calculated. This ensured that known issues of using an artificial scotoma paradigm (i.e., pupil size changes as a result of blinks) were accounted for. This method is designed to reduce known limitations of gaze-contingent scotoma paradigms (Aguilar & Castet, 2011) consistent with previous studies (Harvey, Anderson and Walker, 2019).

Design

Participants completed all of the four conditions (horizontally scrolling text, RSVP, single-line and multiline). One-way Analyses of Variance (ANOVA) were computed to assess reading speed (this was calculated through a custom Python code within Experiment Builder) and reading comprehension which was calculated as the mean average of correct answers and incorrect answers and the number of correct and incorrect literal and inferential answers. The passages and conditions were counterbalanced to control for order effects. None of the participants were presented with the same passage or text twice.

Figure 13

Schematic diagrams of the different text display types, a) shows the single-line static text, b) shows the scrolling text display, c) shows the multiline paragraph format and d) shows the RSVP text display.



Procedure

Participants first completed a short practice session (approximately lasting 2 minutes) before the main experiment. The practice allowed participants to select an appropriate reading speed for the RSVP and scrolling conditions (therefore, speed was different for both dynamic text displays) and to become familiar with the keys for controlling text presentation speed and to familiarise themselves with an artificial scotoma. The YARC primary passage *'Robins'* that consists of 4 sentences in total (designed for 5–11-year-olds) was used for the practice session.

In the main evaluation of reading with a loss of central vision (simulated), participants were asked to read four passages of text that were counterbalanced for all participants across all of the four text presentations (scroll, RSVP, single-line static text and multiline paragraph format). All passages of text were read silently. For the passage presented as scrolling text, participants were able to control the speed at which the text was presented by using arrow keys to make the text scroll faster or slower by 20ms per button press throughout the experiment (i.e., participants had full control over modulating the speed). For the RSVP text display, participants selected an appropriate reading speed during the practice trial, which was then used for the real passage, participants could not change the RSVP speed once selected for this text display.

The speed for all text displays were recorded through a custom Python code in Experiment Builder. For the scrolling, single line static and multiline formats, once the gaze contingent square was triggered, the text appeared on the screen (and timer was started) until the participant pressed the space bar (timer stopped). This pattern continued and allowed participants to progress to the next part of the text until the passage ended.

This enabled the calculation of time spent reading the passage in words per minute. For the RSVP format, once the gaze contingent square was triggered (timer started) the words appeared on screen one after the other until the entire passage had been presented (timer stopped after the last word was presented).

After reading each passage of text, participants were given a list of inferential and literal questions (roughly 10-12 questions). For example, the participant would read *"From a distance, the Honey Guide looks drab and brown, but up close you can see a splash of pale yellow on the white chest feathers."* At the end of the condition, they were asked for example *"what three colours are its feathers?"*). The questions also asked participants to summarise the passage of text that was read (total available points presented in Table 1). This was given straight after the participant had finished reading the passage for which they had no time limit to complete. Breaks were given throughout the experiment and as of when required to prevent fatigue.

Analyses

Analyses of reading comprehension and reading accuracy were conducted using RStudio v 1.1383, 2009-2017 (R Core team, 2014). One-way ANOVA's and paired samples t-tests were attained for display type (scroll, RSVP, single-line and multiline static text), speed (in words per minute, wpm) and comprehension scores split into literal, inference, summary and total scores, the raw scores were converted into percentages.

Results

The data of five participants were excluded from the analyses: two due to scoring zero in the comprehension questions for both dynamic and static text displays (participants were excluded based on the criteria of their data being above or below the overall mean of the total comprehension score, +2.5 SD). A further two participants were excluded due to participants skipping reading trials in the single-line and scrolling text display (missing lines of text from the passage as a result of pressing a key), resulting in inadequate or no eye tracking data. The final participant was excluded as a result of long blinks which again, resulted in poor data quality from the eye tracker. This left data for 14 participants in the final analyses. The final analysis includes an average of reading speed with each text display and one-way ANOVA's and paired samples t-tests to assess comprehension with each text display.

Figure 14

Reading speed in words per minute across the scrolling text display type (~50 wpm), the RSVP text display type (~180 wpm), the single-line text display type (~120 wpm) and the multiline display type (~130 wpm).

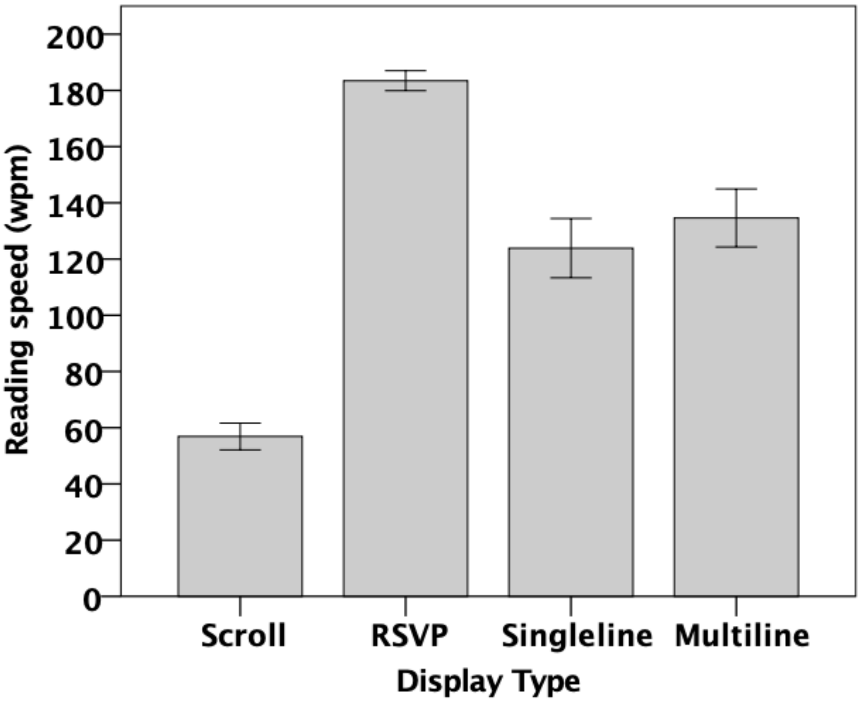


Figure 14 displays the average reading speed (in wpm) for the scrolling text display (*M* = 56.90 wpm, *SE* = 4.76), RSVP (*M* = 183.45 wpm, *SE* = 3.55), single-line static text display (*M* = 123.88 wpm, *SE* = 10.57) and the multiline paragraph format (*M* = 134.61 wpm, *SE* = 10.33). A one-way ANOVA (factors, within subjects) indicated a significant difference between reading speed across all four text display types, F (3, 39) = 69.84, $p < 0.001$, $\eta^2_G = 0.71$. Further analyses using paired samples t-tests showed that reading was the fastest with the RSVP text display compared to the scrolling text display, $t(14) = 27.21$, $p < 0.001$, single-line static text, $t(13) = 5.87$, $p < 0.001$ and multiline paragraph format, $t(13) = 4.71$, $p < 0.001$. Reading with the scrolling text display was the slowest compared to the single-line static text, $t(13) = 8.33$, $p < 0.001$ and the multiline paragraph format, $t(13) = 9.54$, $p < 0.001$. There were no significant differences between the multiline and single-line text displays ($p > 0.05$).

Figure 15

Average Comprehension Question scores (%) across all of the text display types, a) literal based comprehension scores, b) inferential based comprehension scores, c) overall total comprehension and d) summary comprehension scores only.

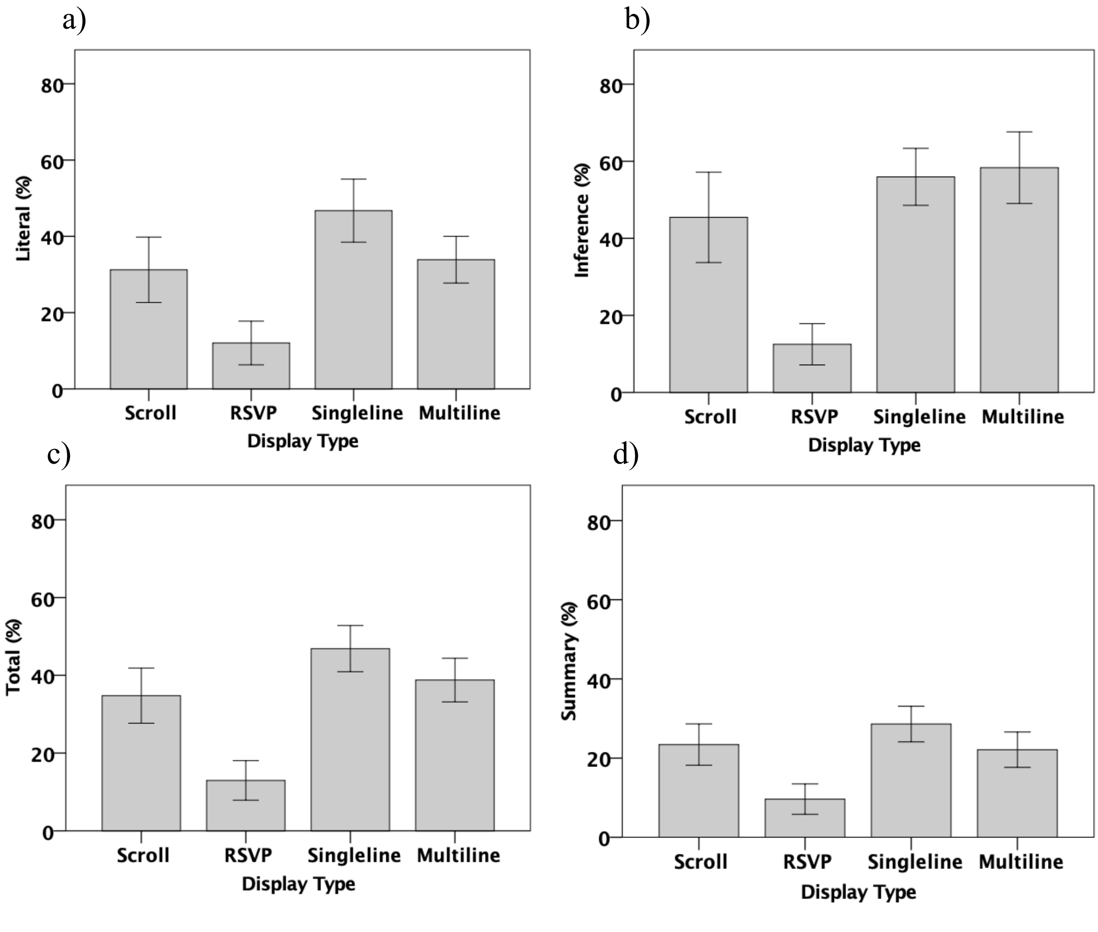


Figure 15a displays the literal comprehension scores for the scrolling text display ($M = 31.22\%$, $SE = 8.57$), RSVP ($M = 12.04\%$, $SE = 5.73$), single-line text display ($M = 46.73\%$, $SE = 8.28$) and multiline paragraph format ($M = 33.88\%$, $SE = 6.12$). A one-way ANOVA indicated an overall significant difference between the percentage of literal based scores across all four text display types, $F(3, 39) = 3.51$, $p < 0.05$, $\eta^2_G = 0.18$.

Further paired samples t-tests indicated that the single-line static text display type resulted in better literal comprehension than the RSVP text display, $t(13) = 4.18$, $p = 0.001$, the multiline paragraph format also resulted in better literal comprehension than the RSVP text display, $t(13) = 2.28$, $p < 0.05$. All other pairwise comparisons were statistically non-significant.

Figure 15b displays the results of the inferential based comprehension scores for the scrolling text display ($M = 45.44\%$, $SE = 11.73$), RSVP ($M = 12.50\%$, $SE = 5.37$), single-line static text ($M = 55.95\%$, $SE = 7.38$) and multiline paragraph format ($M = 58.33\%$, $SE = 9.29$). A one-way ANOVA indicated a significant difference between the percentage of inference-based question scores within each text display type, $F(3, 39) = 6.01$, $p < 0.01$, $\eta^2_G = 0.25$. Additional paired samples t-tests indicated that the scrolling text display resulted in significantly better inferential based scores than the RSVP text display, $t(13) = 2.35$, $p < 0.05$. The single-line static text display also resulted in better inferential comprehension than the RSVP text display, $t(13) = 4.74$, $p < 0.001$ and the multiline paragraph format also resulted in better inferential comprehension than the RSVP text format, $t(13) = 4.61$, $p < 0.001$. All other pairwise comparisons were statistically non-significant.

Figure 15c shows the total comprehension scores (overall reading comprehension) for the scrolling text display ($M = 34.76\%$, $SE = 7.11$), RSVP ($M = 12.97\%$, $SE = 5.09$), single-line static text display ($M = 46.85\%$, $SE = 5.94$) and the multiline paragraph format ($M = 38.77\%$, $SE = 5.61$). A one-way ANOVA indicated a significant difference between the total percentage of scores achieved within all four text display types, $F(3, 39) = 5.96$, $p < 0.01$, $\eta^2_G = 0.25$. Paired samples t-tests indicated that the scrolling text display resulted in better overall comprehension than the RSVP text display, $t(13) = 2.37$, $p < 0.05$. The single-line static text also resulted in better comprehension than the RSVP text display, $t(13) = 5.08$, $p < 0.001$ and the multiline paragraph format also resulted in better comprehension than the RSVP text display, $t(13) = 3.59$, $p < 0.01$.

Finally, Figure 15d represents the summary scores for the scrolling text display type ($M = 23.41\%$, $SE = 5.23$), RSVP ($M = 9.64\%$, $SE = 3.84$), single-line static text ($M = 28.59\%$, $SE = 4.50$) and multiline paragraph format ($M = 22.12\%$, $SE = 4.48$). A one-way ANOVA indicated a significant difference between the summary scores across all four text display types, $F(3, 39) = 4.33$, $p < 0.01$, $\eta^2_G = 0.15$. The paired samples t-tests indicated that the scrolling text display resulted in better summary scores than the RSVP text display, $t(13) = 3.07$, $p < 0.01$ and again, the single-line static text display resulted in better summary scores than the RSVP text display, $t(13)$, $= 2.93$, $p < 0.05$ and this was also the case with the multiline format and RSVP, $t(13) = 2.62$, $p < 0.05$.

Discussion

Experiment 1a aimed to examine reading performance with a simulated CVL (using a gaze contingent artificial scotoma paradigm) with text presented dynamically; single line of text scrolling horizontally and RSVP and static text; single line of static text and multiple lines of static text. The main outcome measure was reading comprehension which was divided into; literal based comprehension, inferential based comprehension, overall comprehension (literal and inferential combined) and summary points. An average of reading speed was also calculated to assess reading rate with all four text presentations. It was hypothesised that reading comprehension would be better with the dynamic text displays (especially scrolling text) compared to the static text displays (single-line static text and multiple lines of text) with an artificial CVL.

In contrast to the hypothesis that dynamic text presentation will result in better reading comprehension than static text, the results showed that reading comprehension was much poorer with the dynamic texts (RSVP and scrolling text display) compared to the static formats (single-line and multiline displays). The RSVP text display had the poorest comprehension overall compared to all other text display formats, despite the elimination of eye movements. The findings of this experiment contradict previous studies which have found dynamic text presentation to improve reading comprehension (e.g. Rubin & Turano, 1992; Walker et al., 2016). Although the reading comprehension was poor with RSVP; the results are somewhat supportive with Rubin and Turano (1994) where it was found that with participants with low vision (central field loss), although RSVP resulted in faster reading speeds, it also led to a decrease in reading improvement. Here, we see that although RSVP was read the fastest, it also resulted in the poorest comprehension. The slow reading speed observed with scrolling text may be as a result of a lack of practice to read with this format as well as participants adjusting to reading with an artificial scotoma.

A possible confound of this experiment is that firstly, participants were not required to read aloud, therefore it is unclear as to whether participants were actually reading the text itself. Reading silently may be problematic as it results in challenges in evaluating reading rate (Rubin, 2013). The fact that some participants scored a total of zero across all four text displays suggest that they were not reading however, it is also unclear as to whether participants were paying attention and actually reading. Previous research has suggested that people with macular degeneration read faster when they read silently compared to reading aloud however, when participants read silently over a longer period of time reading was the same rate as to a set of controls. Despite this, comprehension was poorer demonstrating that reading comprehension was compromised over speed (Varadaraj et al., 2018). In this experiment it could be possible that participants also prioritised reading speed over comprehension.

Another confound is the manipulation of the rate at which text is presented which was set by the participants. For the scrolling text display participants were able to manipulate the speed as of when they wanted to, leading to different speeds across participants and further resulting in different speeds with RSVP. The ability to manipulate the speed of the scrolling text throughout the experiment and not the RSVP text display results in confounds of variability within both of these dynamic text formats. Previous studies have found that RSVP can be read at rates of 1000 wpm or more (Forster, 1970; Rubin & Turano, 1992) however, with scrolling text such high reading rates are not possible as a result of firstly, the inability to track text leftwards and make rightward saccades and secondly, perceptual blurring (Slattery & Rayner, 2010). Previous research showed that an upper limit of 250 wpm was appropriate for readers who were normally sighted (Harvey, Anderson & Walker, 2019; Harvey et al., 2017). For readers with a loss of central vision, reading is more challenging with scrolling text and previous research has suggested that people with CVL read normal text at a much slower rate (80-120 wpm) (Harvey, Anderson & Walker, 2019; Wiecek et al., 2014). As a result, a lower limit of reading speed was selected for both text displays. A second study was therefore performed to address these concerns. Participants were required to read aloud to ensure they engaged with the task and the on-line speed manipulation was not used with the scrolling text format. Instead, the rate of text presentation was set in a practice session and matched for the scrolling and RSVP formats.

Experiment 1b. Reading with a simulated scotoma with static and dynamic text displays with fixed rate of presentation.

Introduction

Experiment 1b was a replication of Experiment 1a but without the user manipulation of speed of text presentation. A potential problem with Experiment 1a was that participants were able to manipulate the speed during the scrolling text display whilst they were reading the passage. This is problematic for numerous reasons. For instance, the speed manipulation introduces a confound in the scrolling and RSVP text display comparisons, where differences in comprehension are not as a result of the display format but rather the speed, as large differences in rate of presentation were observed. Thus, comprehension may have depended on, to some extent, on the speed of presentation and reading. Moreover, the speed manipulation in one text display and no speed manipulation in another text display results in variance between the text displays and provides an inaccurate measure of reading performance.

To address these issues, in this experiment the text presentation rate was set for each participant during the practice trial which was selected by the participant at a speed they felt comfortable reading at. This speed was then set for the test phase for each participant. The speed set for the scrolling text display was then matched to the RSVP text presentation rate as close as possible. Therefore, the scrolling text display and RSVP text display were set at similar rates thus, controlling for the potential trade-off between speed and accuracy.

This study aimed to firstly, examine whether the eccentric viewing strategy could be adhered to when reading with an artificial central scotoma across dynamic (horizontally scrolling text and RSVP) and static text (single-line and multiline paragraph format) displays. Secondly, eye movement behaviour will be examined to assess the oculomotor strategy adopted when reading with the eccentric viewing strategy across all of the text presentations. Thirdly, reading performance will be assessed with the different text presentations to assess how reading with eccentric viewing affects reading performance with the dynamic and static text presentations. Finally, this study will be replicated with people who have an actual loss of central vision (Chapter 3), it will be determined whether findings from this laboratory-based study with an artificial central scotoma can be generalised to people with an actual loss of central vision.

The hypotheses of this study were firstly, participants will be better at maintaining an eccentric viewing position with the dynamic text presentation (scrolling and RSVP) compared to the single line static text. Secondly, dynamic text presentation will result in better reading performance with scrolling text (reading comprehension and reading accuracy) compared to other formats (RSVP and static text) in participants with an artificial scotoma as a result of potentially enhancing the adoption of the eccentric viewing strategy.

Method

Participants

Fifteen students (11 female and 4 male) aged from 18 - 32 years (*M* = 20.40, *SD* = 3.94) were recruited from Royal Holloway, University of London. The participants reported to have normal or corrected to normal vision (best corrected binocular visual acuity of 0.0logMAR or better), reported English as their first language, and had self-reported having no language or reading deficits. All of the participants gave written informed consent prior to participating within the study. The study was reviewed and approved by the College Ethics Committee at Royal Holloway, University of London (see Appendix 1).

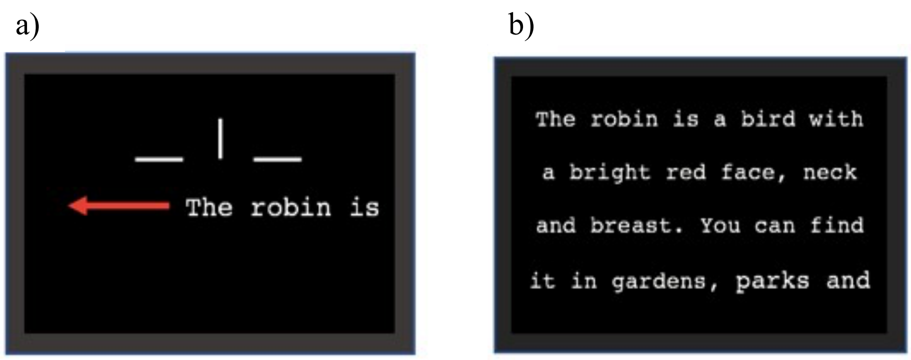
Stimulus and Apparatus

The stimulus and apparatus were the same as Experiment 1a, including the gaze contingent artificial scotoma, except for Experiment 1b, the position of the gaze contingent square to initiate the text was moved to match the guideline presented. For the single line static display, the eccentric fixation was to the left edge of the screen and for the RSVP and scrolling text presentations this was located eccentrically in the centre of the screen. In addition, the size of the font was set to 36point (visual angle = 0.71°, 28 pixels horizontal character size), this was based on a previous pilot. Additionally, for Experiment 1b, the practice passages were longer (approximately 82 words) to allow participants to familiarise themselves with the different text displays and the artificial scotoma. The practice trial included a children's story 'Turtle'. This was taken from an online open book source (http://magicblox.com).

All presentations of text displays were the same as Experiment 1a however, for the scrolling text (see Figure 16a) the guideline was presented as a fixating cross to match the RSVP condition. This was to help aid and guide the participants to adopt the eccentric viewing position, further allowing to adopt the steady eye strategy. The multiline static format (see Figure 16b) was presented as four lines (due to the smaller font size an additional line was able to fit on the screen rather than three lines which was the case with Experiment 1a). In addition, the speed of the text presentation for the scrolling and RSVP conditions were matched for each participant during the practice session.

Figure 16

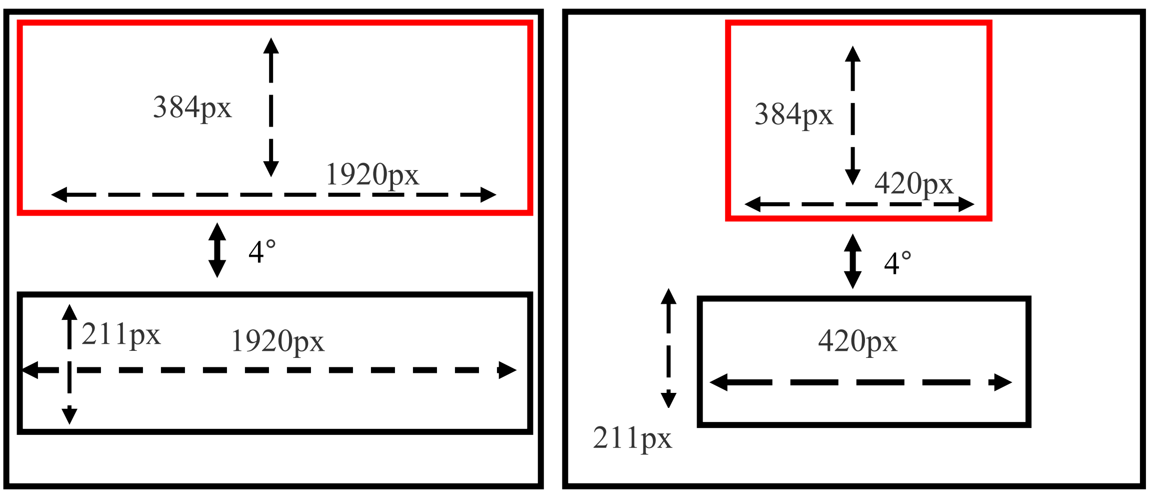
Schematic diagram of the a) scrolling text display type with the cross guideline, b) multiline text display type, consisting of four rows of text which were double spaced.



Furthermore, the apparatus and methods were the same as Experiment 1a except for Experiment 1b, Regions of Interest (ROI) were drawn for the static single line, scrolling and RSVP text displays. There were two ROIs drawn (see Figure 17) for each of these three text displays which were defined within the script used to analyse eye movement data. For the scroll and single line static text displays the size of the ROI was the radius length above the text, 1920 (width) x 384 (height) pixels. The text region of interest was 1920 (width) x 211 (height) pixels. For the RSVP text display the width of the ROI was 420 pixels, covering the longest word presented (15 characters) and the height was 384 pixels. The text region of interest was 420 pixels (width) x 211 pixels (height). Both ROI's were located 4° above the text region of interest (see Figure 17). The ROI guideline was positioned 4° above the text region of interest to enable a full view of the text in the peripheral visual field when participants fixated on the guideline. The location of fixations was classified in line with these ROIs drawn (i.e., fixations made in the eccentric region and fixations made in the text region).

Figure 17

Schematic diagrams showing region of interests (ROIs). Left shows the ROIs for the scroll and single line static text presentations. The eccentric viewing ROI (red) covered the radius length of the text presented (1920 pixels) and the height of the eccentric viewing ROI was 384 pixels. The text ROI (black) for the scroll and single line static text presentations were 1920 pixels (width) and 211 pixels (height). The diagram on the right represents the RSVP text display, the eccentric viewing ROI (red) was 420 pixels (width) and 384 pixels (height) and the text ROI was 420 pixels (width) and 211 pixels (height). For all text display types, the eccentric viewing ROI was positioned 4 degrees above the text ROI.



Procedure

The procedure was replicated from Experiment 1a except here the participants' speeds for the scrolling condition and RSVP condition were matched and participants did not control the speed during the experiment. During the practice trials participants selected a speed at which they felt comfortable reading at, this was then used for that participant during reading of the real passages. The scrolling text display was always given first in the practice and main session before the RSVP text display. This was because during a separate pilot study it was evident that RSVP can be read at a faster speed which would not be suitable for scrolling text. Therefore, the speed of the RSVP text was matched as close as possible to the scrolling text display (i.e., they were matched as close to possible to one another).

All four conditions including the practice trials for each condition were completed in one session lasting around 5 minutes, breaks were given throughout the experiment when needed. All participants were informed about the eccentric viewing strategy and were prompted during the practice to try and implement the strategy. This was reinforced before the actual experiment and a few prompts were given during the experiment to encourage participants to adopt the strategy, after a few prompts, participants were not prompted again. Participants were instructed to read aloud and were recorded using a voice recorder in order to allow scoring of reading accuracy after the experimental session. Participants completed the YARC comprehension questions after reading with each text display (see Table 1). A measure of reading error rates (classified as words which were missed, substituted or read incorrectly whilst reading the passage) were also included. Error rates were converted into an overall percentage for each text display type. The passages and text display types were counterbalanced to control for order effects. None of the participants were presented with the same passage or text display twice.

Results

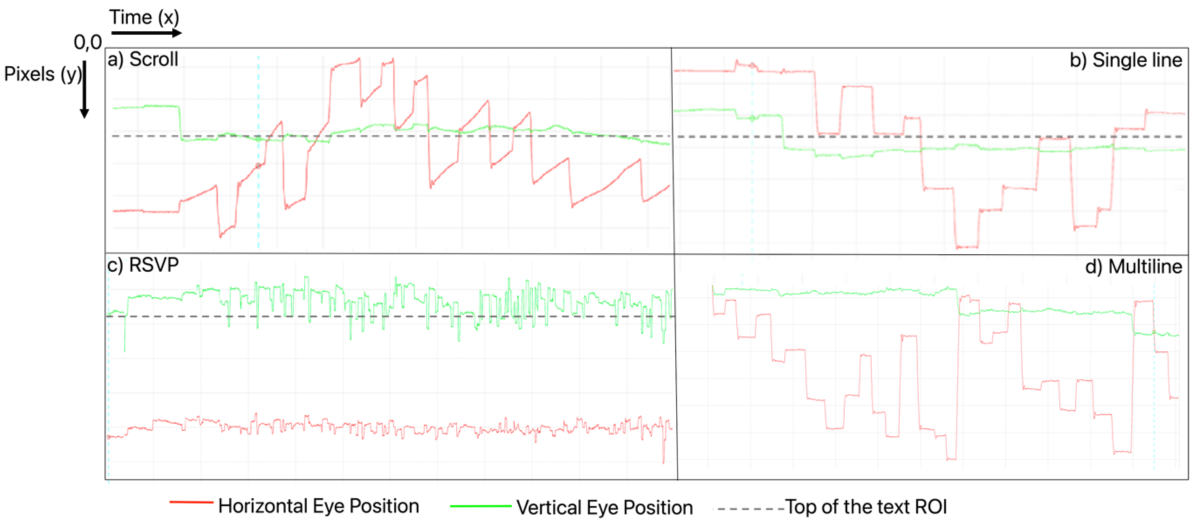
Analyses were carried out using SPSS (IBM Statistical Package for the Social Sciences) to analyse eye movements (adherence to eccentric viewing) and reading comprehension in percentages, reading accuracy in percentages and reading speed in words per minute (wpm). The eye movement data (average number of saccades made, saccade amplitude, average number of saccades made per sentence, fixation duration and proportion of fixations made eccentrically) were analysed using RStudio v 1.1383, 2009-2017 (R Core team, 2014). The data was cleaned to exclude trials where participants failed to read any of the sentences, trials were adjourned early or there appeared to be a failure of calibration during the trial. This resulted in the exclusion of 4 participants resulting in the final data containing a total of 15 participants.

Eye movement analysis

Figure 18 displays examples of x-y plots of eye movement trials of one participant when reading with each text display presentation (scrolling text, single-line static text, RSVP and multiline paragraph format). The eye patterns shown in Figure 18 typically represents the oculomotor movement observed consistently across all of the participants in the study with the exception of some participants showing better maintenance of holding their gaze eccentrically. In Figure 18 the green line represents the vertical eye position (i.e., an upwards line shows a saccade which was made upwards and a downwards saccade represents a saccade made which was made downwards). The red line in the Figure shows a horizontal eye position (i.e., an upward line indicates a saccade which was made leftwards, and a downward line indicates a saccade which was made rightward). The grey line represents the top of the text region, when the green vertical eye trace is on the grey dashed line this indicates that fixations were made by the participants onto the text.

Figure 18

Typical eye movement trace examples from a participant when reading with a) horizontally scrolling text, b) single-line static text, c) RSVP text display and d) multiline paragraph format. The x-axis represents time, the y-axis represents location (in pixels) with the top left corner of the display being (0,0). The green line indicates the vertical eye position where an upward line movement indicates a saccade made upwards and a downwards line movement represents a downward saccade. The red line indicates the horizontal eye position, where an upwards line movement represents a leftward saccade (either pursuit or saccade) and a downwards line movement represents a rightward saccade. The grey dashed line indicates the top of the text region of interest.



The eye movement traces show that for scrolling text (Figure 18a) the initial fixation was executed on the central fixation cross at the preferred eccentric viewing location. As the text appears, vertical shift made downwards is observed, positioning the gaze onto the line of text where it remained for the duration of the trial. The horizontal trace indicated that after an initial period of fixation a tracking movement was observed leftward as soon as the downward movement happened. After this, a sequence of saccades made to the right and pursuit movements made to the left were observed which were confined to the left and the centre of the screen. The single-line static text (18b) eye movement trace generally showed poor maintenance of the eccentric viewing technique. Again, initially a vertical saccade is executed onto the text proceeded by numerous leftward and rightward saccade (like a seesaw manner) across the text. With the RSVP text display (18c) the eye movement trace represents the entire passage as the RSVP passage was recorded as one whole trial. The eye movement trace here indicated a pattern of upwards and downwards saccades with fewer leftward and rightward saccades. However, generally the eye movement trace shows relatively better maintenance to the eccentric viewing strategy. Finally, 18d shows the multiline paragraph format, the eye movement trace here indicates again a seesaw like pattern of leftward and rightward saccades along the text. Overall, the eye movement traces observed in Figure 18 are similar to the eye movement behaviour pattern which is typically seen for reading with dynamic and static text with normal vision.

To examine how well participants adhered to the eccentric viewing technique, analysis was conducted on the average for the average number of saccades made (horizontally and vertically, classified as pursuit and saccades), the average saccade amplitude (measured in degree of visual angle), average fixation duration (ms), the average fixation positions for all of the participants, the individual fixation positions for each participant for the scrolling and single-line static text display. These two formats were of interest as they were spatially comparable and were displayed in a similar manner (a line of static text and a line of horizontally scrolling text). Fixations and saccades were defined using the Experiment Builder and Data Viewer software and in accordance with the ROIs drawn.

Figure 19

Eye movement data, a) the average number of horizontal saccades (for scrolling text, leftward movements were recorded as pursuit tracking) and vertical saccades for the scrolling and single-line static text displays, b) The average saccade amplitude made horizontally (rightwards and leftwards) and vertically (upwards and downwards) for the scrolling and single-line static text displays (measured in degrees of visual angle), c) mean number of saccades made per sentence for the scrolling and single-line static text displays.

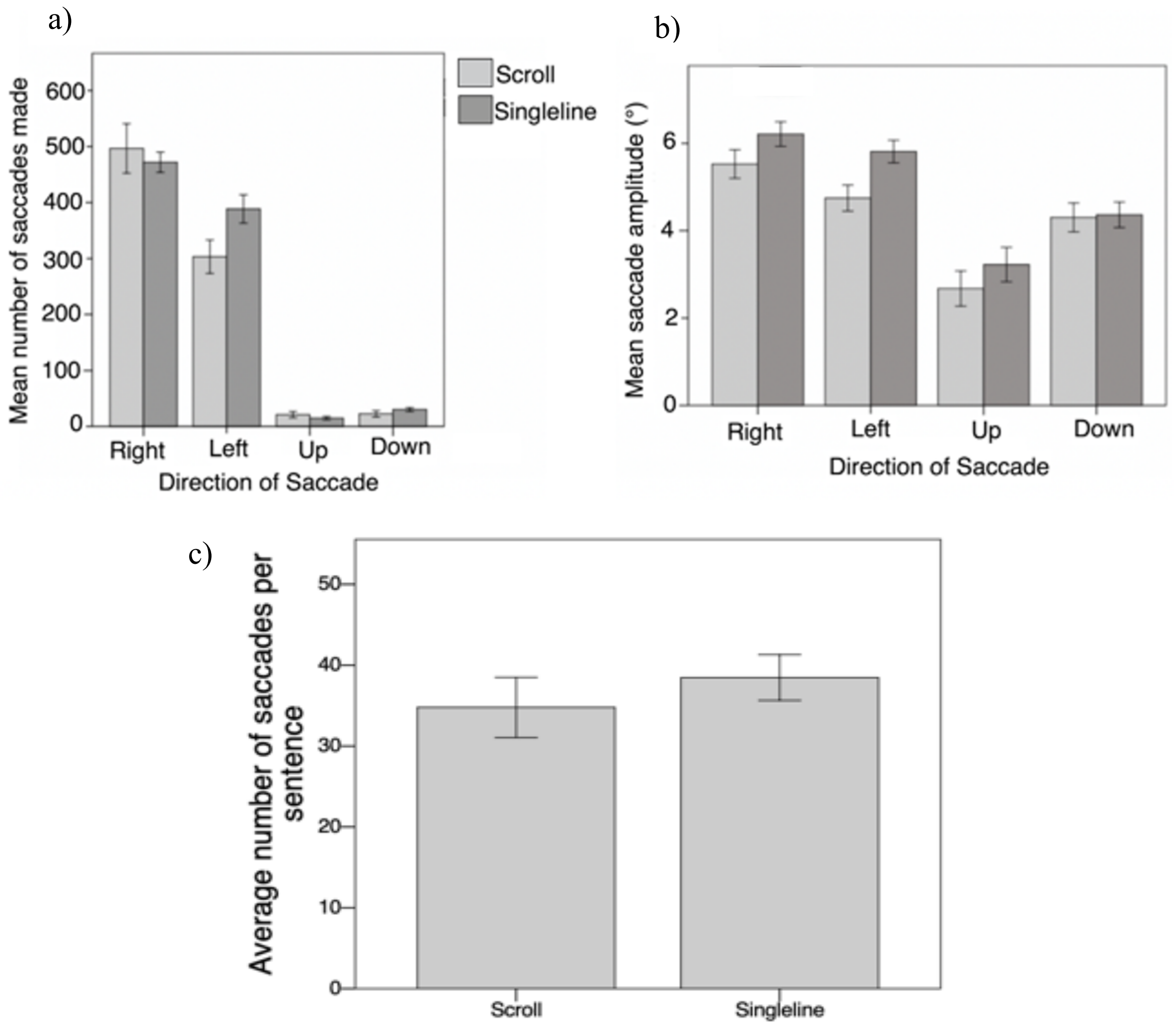


Figure 19 displays the mean number of both horizontal and vertical saccades made, the mean saccade amplitude (measured in degrees of visual angle) and the mean number of saccades that were made per sentence for the scrolling and single-line static text displays. Typically, from Figure 19 it is observed that the most saccades which were made were horizontal with a small proportion of the saccades being made vertically between the eccentric viewing region of interest and the text region of interest. For both text displays there were a number of leftwards and rightwards saccades which were made during reading. This is typically the general pattern when reading with normal vision however, here there are slightly less leftward saccades which were made. From the saccade amplitude it can be observed that the leftward and rightward saccade amplitude is consistent for both text displays (around 5-6^{o}). This supports the eye movement traces observed in Figure 18 which indicated that participants tried to sample the text by making multiple leftward and rightward eye movements on the text. As also seen in the eye movement trace in Figure 18, there are a small proportion of saccades made vertically which is observed when participants make an initial saccade downwards onto the text (around 4^{o}) with attempts of moving gaze upwards (i.e., making a small saccade upwards above the text) to try and adhere to the eccentric viewing technique.

For analyses a repeated measures 2x4 (display type; scroll and single-line and direction of saccade; right, left, up and down) ANOVA was conducted to examine the mean number of saccades which were made horizontally (leftward and rightward) and vertically (upward and downward). There was an overall significant effect of number of saccades and direction of saccade, $F(3,42) = 143.64$, $p < 0.001$, $\eta^2_G = 0.91$, an effect of display, $F(1,14) = 74.83$, $p < 0.001$, $\eta^2_G = 0.84$ and finally an overall interaction of direction of saccade and display type, $F(3,42) = 25.91$, $p < 0.001$, $\eta^2_G = 0.21$. The results showed that there were significantly more saccades which were made to the left with the single-line static text display ($M = 388.47$, $SE = 25.41$) than the scrolling text display ($M = 303.20$, $SE = 29.89$), $t(14) = 3.08$, $p < 0.01$. Further pairwise comparisons indicated that there were significantly more saccades made to the right with the scrolling text display ($M = 496.60$, $SE = 44.15$) than to the left ($M = 303.20$, $SE = 29.89$), $t(14) = 6.80$, $p <$

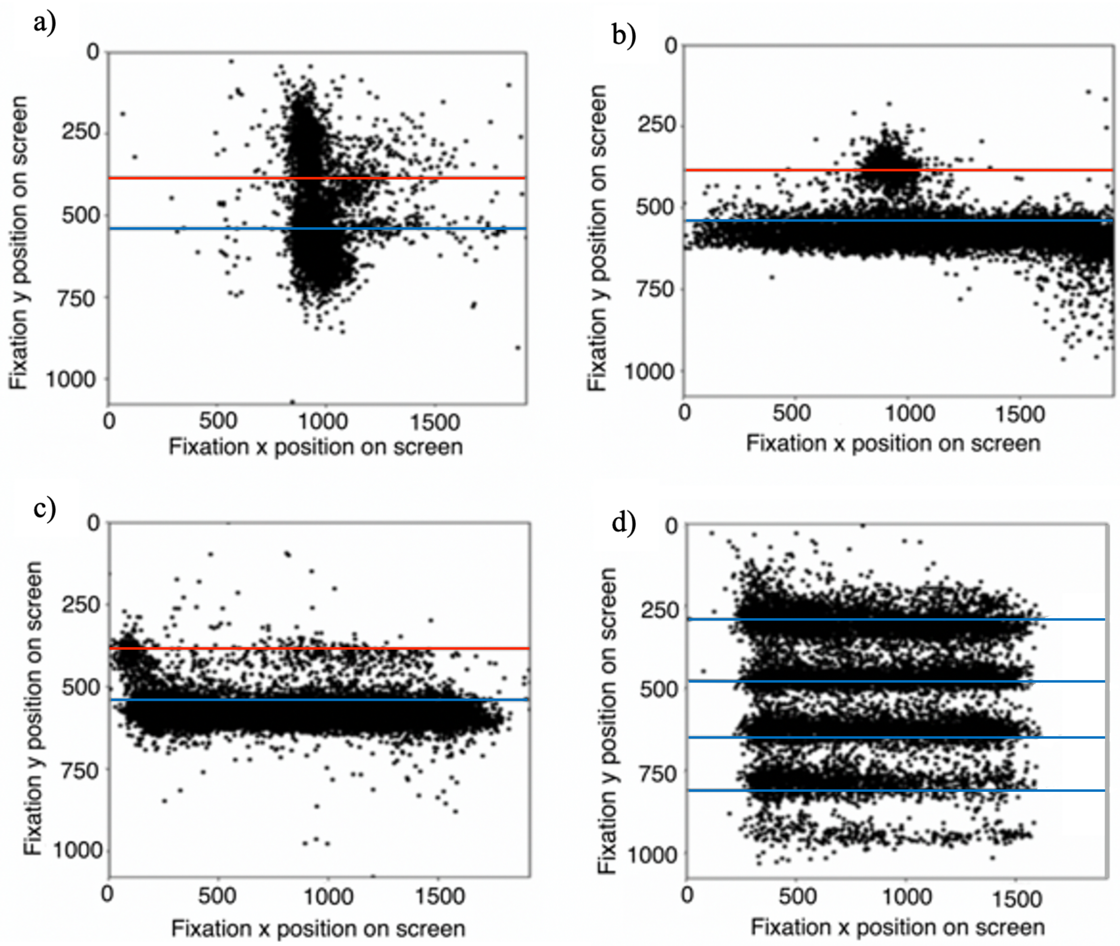
0.001. For the single-line static text display, participants made more saccades towards the right (M = 472.00, SE = 17.97) than to the left (M = 388.47, SE = 25.41), $t(14) = 4.48$, $p = 0.001$ and more downwards (M = 30.20, SE = 3.43) than upwards (M = 14.80, SE = 3.13), $t(14) = 5.51$, $p < 0.001$; making significantly more saccades to the left with the single-line static text display than the scrolling text display, $t(14) = 3.08$, $p < 0.01$.

In addition, there was an overall significant effect of display type (scroll and single-line), $F(1,28) = 77.27$, $p < 0.001$, $\eta^2_G = 0.73$, direction, $F(1,28) = 6.40$, $p < 0.001$, $\eta^2_G = 0.19$ and an overall interaction between display type and direction of saccade on saccade amplitude, $F(1,28) = 8.25$, $p < 0.001$, $\eta^2_G = 0.21$. Pairwise t-tests indicated that the saccade amplitude was significantly higher for leftward saccades with the single-line static text display than the scrolling text display, $t(14) = 2.66$, $p = 0.02$. However, there were no significant differences for rightward directed saccade amplitude ($p = 0.08$). For the scrolling text display, saccade amplitude was significantly higher for rightward saccades (M = 5.53, SE = 0.33) than leftward (M = 4.75, SE = 0.30), $t(14) = 2.22$, $p < 0.05$. For the vertical saccades, saccade amplitude was higher with downward saccades (M = 4.30, SE = 0.33) than upward saccades (M = 2.68, SE = 0.40), $t(14) = 2.76$, $p < 0.05$. For the single-line static text display, saccade amplitude was higher for downward saccades (M = 4.36, SE = 0.29) than upward saccades (M =3.23, SE = 0.39), $t(14) = 3.06$, $p < 0.01$. There were no overall significant differences for the number of saccades made on average per sentence for the scrolling and static text ($p = 0.44$).

Adherence to eccentric viewing

Figure 20

Plots displaying the individual fixation positions across all participants with the a) RSVP text display, b) scrolling text display, c) single-line static text display and d) multiline paragraph format. The first horizontal line (red) represents the eccentric viewing region of interest and the second horizontal line (blue) displays the text region of interest.



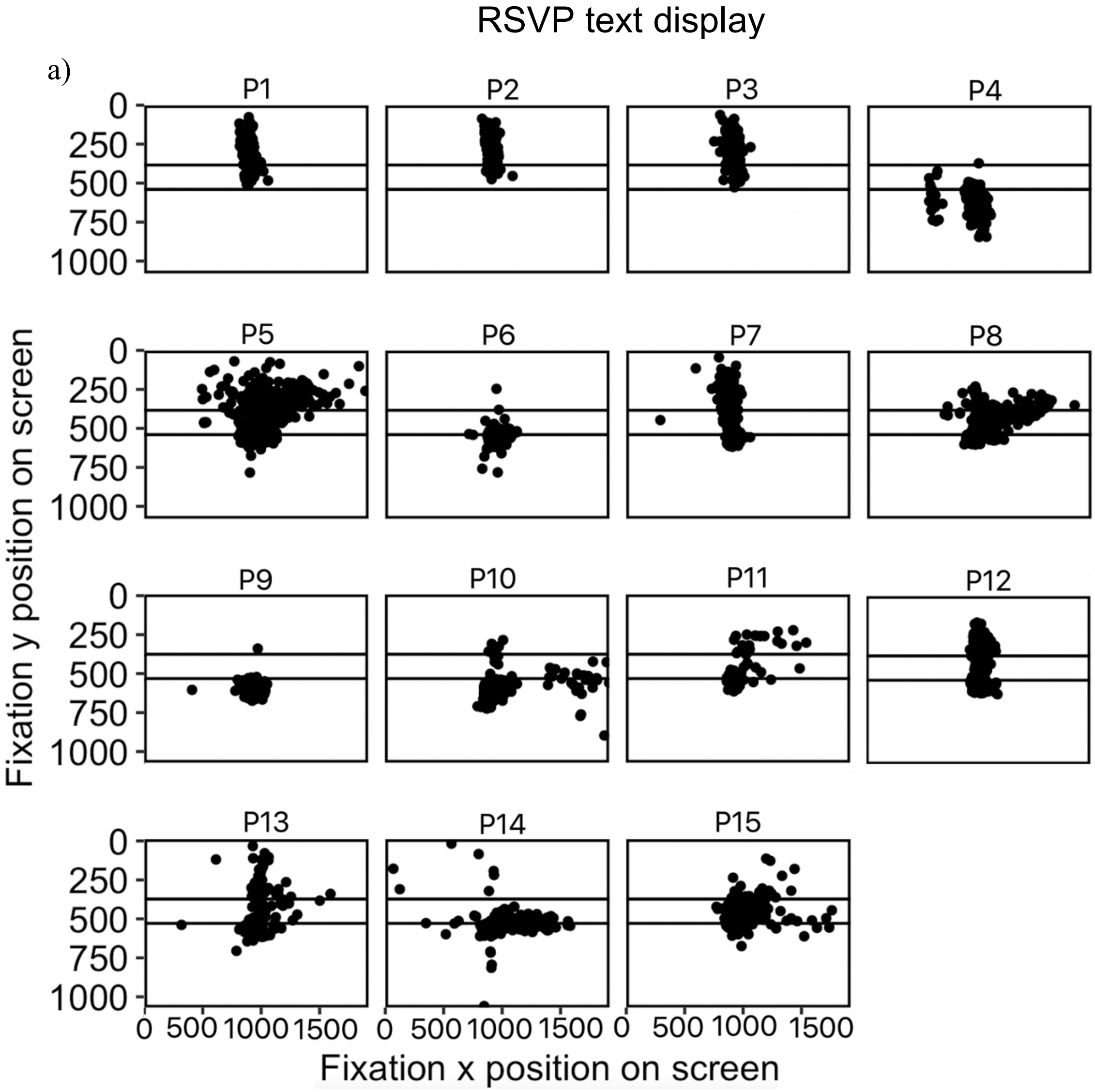
The individual fixation plots displayed in Figure 20 show fixations which were made by all participants when reading with each of the text display presentations. As observed with the eye movement traces in Figure 18, these plots are consistent with the eye movement traces. A large proportion of fixations are observed with the scrolling and static text presentations occur on the text (the text region of interest) and less within the eccentric viewing region of interest. On the other hand, with the RSVP text display there are more fixation in the eccentric viewing region of interest indicating that participants were better able to maintain the eccentric viewing strategy with this text display compared to the static and scrolling text displays. This observation suggests that participants found it challenging to maintain the eccentric viewing strategy and reverted to looking at the text regardless of the 8-degree scotoma blocking central field of view. This demonstrates that participants engaged in an oculomotor behaviour which was not effective. The general pattern observed in Figure 20 displays participants making multiple horizontal eye movements on the text itself or in the text ROI instead of in the eccentric ROI (thus adopting the eccentric viewing strategy) as they were instructed to do so. This oculomotor pattern is counterproductive and ineffective as a result of the artificial central scotoma. It is possible that participants instead may be attempting to read the words at the edge of the scotoma itself, again confirming the difficulties of adopting a new oculomotor strategy and overcoming the strong natural tendency of shifting gaze and attention onto the desired target to allow for foveal processing.

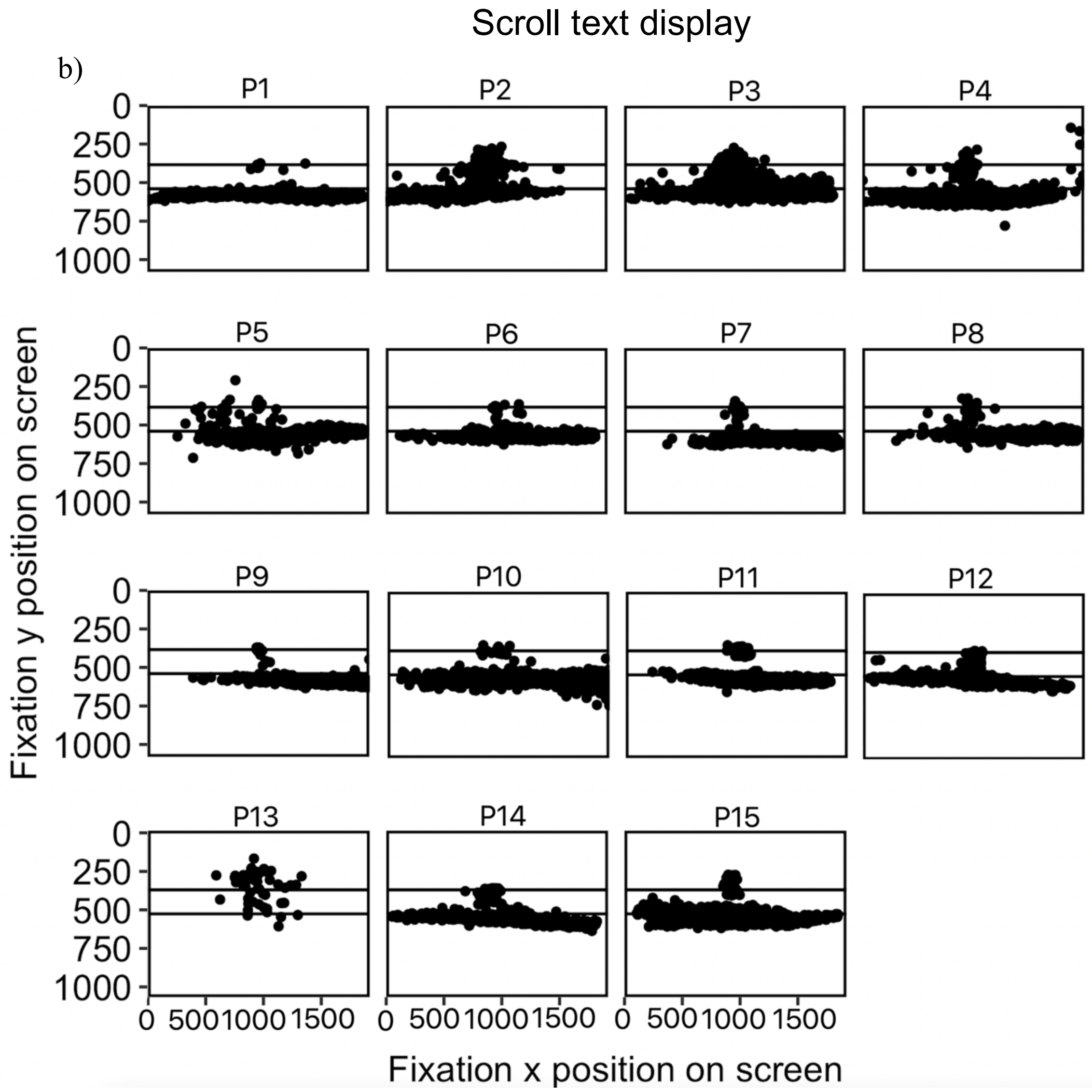
A 3x2 ANOVA (display type vs ROI) was computed for fixation count. There was a main significant effect of display type on fixation count, $F(2,28) = 25.18$, $p < 0.001$, $\eta^2_G = 0.64$, ROI, $F(1,14) = 237.54$, $p < 0.001$, $\eta^2_G = 0.94$ and a significant interaction between display type and ROI with fixation count $F(2,28) = 26.40$, $p < 0.001$, $\eta^2_G = 0.65$. Further paired samples t-tests indicated that there were significantly more fixations made on the text region with the scrolling text display (*M* = 834.47, *SE* = 72.59) than the RSVP text display (*M* = 359.60, *SE* = 65.48), $t(14) = 5.93$, $p < 0.001$, significantly more fixations on the text region with the single-line static text display (*M* = 936.53, *SE* = 40.84) than the RSVP text display, $t(14) = 6.55$, $p < 0.001$. There were no statistically significant differences of fixation count on the text ROI between the scrolling and single-line static text displays ($p = 0.22$).

Figure 21

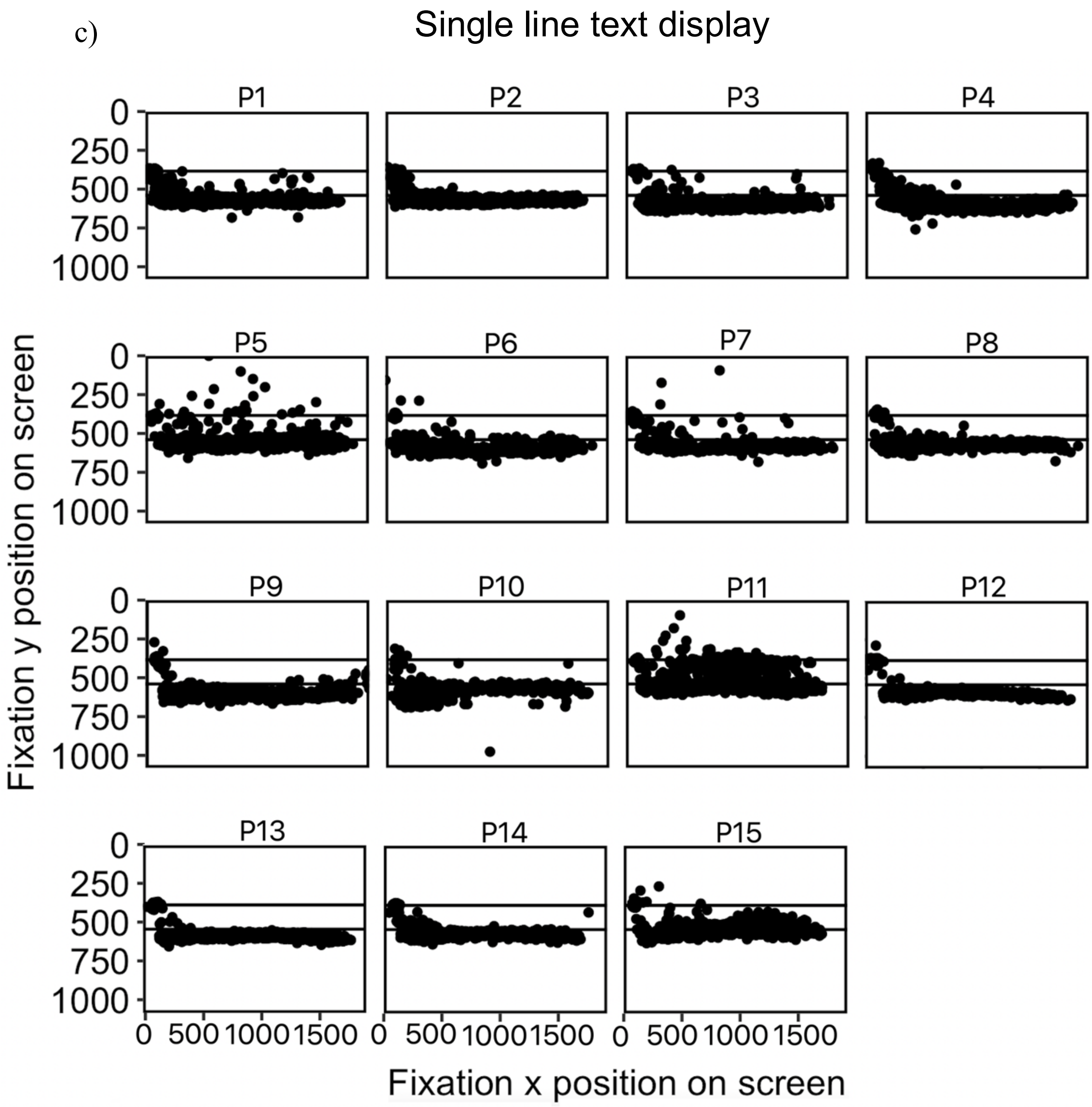
Fixation positions for each participant and text display type, a) RSVP text display, b) scrolling text display and c) single-line static text display. The top guideline represents the eccentric viewing region of interest and the bottom line represents the text region of interest.

a)




Scroll text display
b)
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
0
250
500
750
1000
0 500 1000 1500
Fixation y position on screen
Fixation x position on screen

c)



The fixation plots displayed in Figure 21 indicate some participants attempting to adhere to the eccentric viewing strategy (i.e., holding gaze eccentrically). However, as mentioned the individual plots confirm that the majority of fixations are on the text itself with the scrolling and single-line static text displays. However, with the RSVP text display, the majority of participants show a relatively good attempt of adhering to the eccentric viewing strategy. It is also important to note that participants 2, 3, 11 and 13 displayed good attempts of adopting the eccentric viewing strategy with the scrolling text display (fixations are observed in the eccentric region). On the other hand, this is not observed with the single-line static text display. It is clear that participant 13 in particular with the scrolling text showed clear evidence of adhering to the eccentric viewing strategy by holding gaze continually (88.4% of the time) in the eccentric region with the scrolling text display. However, with the RSVP text display participant 13 spent 8.69% of the time eccentrically viewing and considerably even less with the single line static text display (1.93%). This shows the potential benefits for the dynamic text displays however despite this, the majority of participants adhered poorly to the eccentric viewing strategy.

To examine how well participants maintained the eccentric viewing strategy, the proportion of time (analysed as percentage of total time spend eccentrically reading) spent eccentrically fixating was calculate for the RSVP, scrolling and single-line static text displays. In addition, the average fixation duration (ms) was calculated for each of the text displays (RSVP, scroll and single-line static text). The multiline paragraph was not included as an eccentric region was not suitable for this format as reading with this format involves vertical and horizontal shifts of gaze and is not directly comparable to the single vertical position of text in the other three conditions which are spatially similar.

Figure 22

a) The proportion of time (in percentage) spent fixating in the eccentric viewing region of interest for the RSVP text display, scrolling text display and the single-line static text display, b) average fixation duration (ms) for the RSVP, scrolling and single-line static text displays.

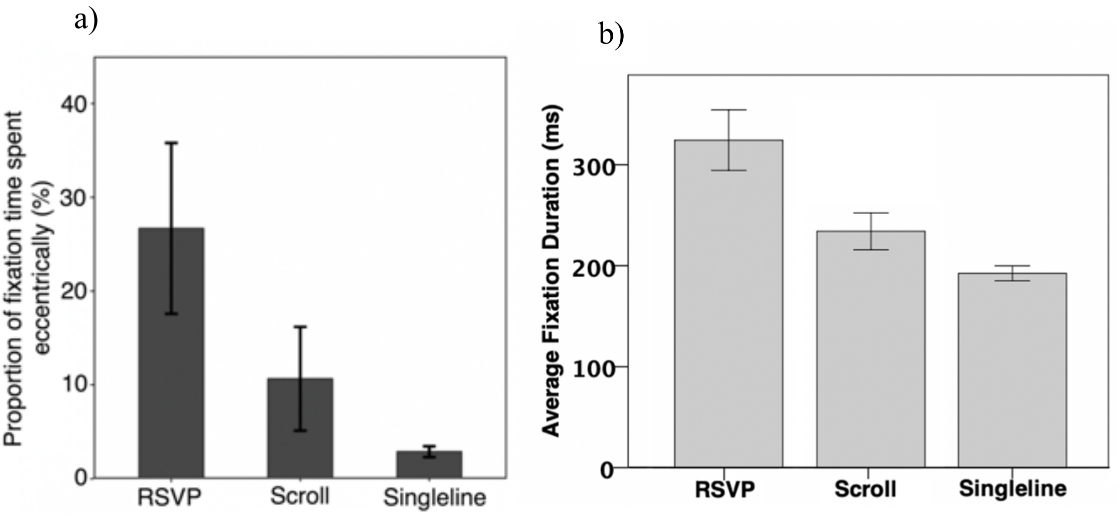


Figure 22a displays the proportion of time participants spent fixating eccentrically for each of the text displays. A one-way ANOVA and paired samples t-tests were computed to assess the time spent eccentrically viewing for each text display. Overall, there was a significant effect of text display on the adherence of ability to hold gaze at the eccentric location in the ROI, $F(2, 30) = 4.02$, $p < 0.05$, $\eta^2_G = 0.22$. The RSVP text display (M = 26.69%, SE = 9.10) had significantly better maintenance of eccentric viewing than the single-line static text display (M = 2.89%, SE = 0.58), $p < 0.05$, but there was no difference between the scrolling text (M = 11.17, SE = 5.89) display and RSVP ($p = 0.19$) or static text ($p = 0.18$).

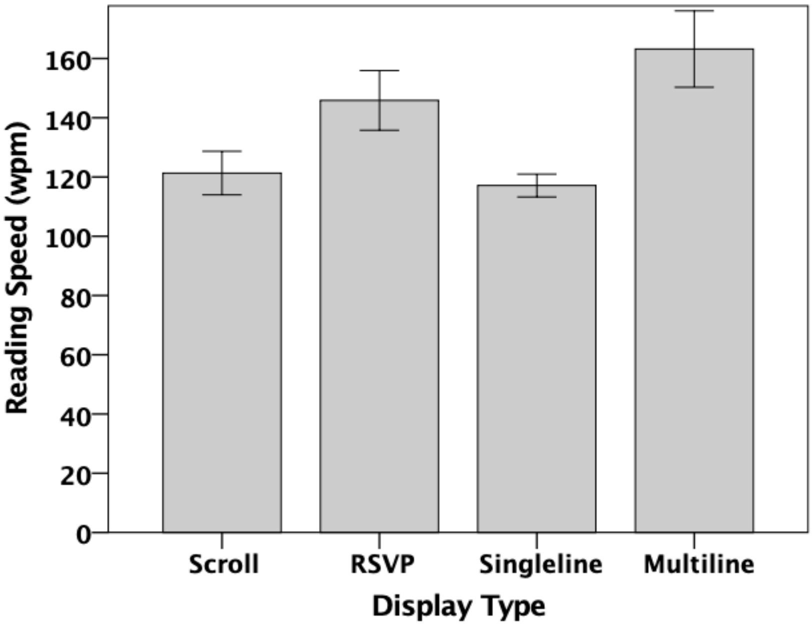
Figure 22b displays the average fixation duration (ms) in for all three text displays. An ANOVA indicated that there was a significant difference of fixation duration with each text display type $F(3, 42) = 9.21$ $p < 0.01$, $\eta^2_G = 0.32$. Further pairwise t-tests indicated that fixation duration was significantly longer with the RSVP text display (M = 365.21, SE = 45.18) than the scrolling text display (M = 231.07, SE = 28.07), $t(14) = 2.52$, $p < 0.05$ and single-line static text display (M = 104.94, SE = 8.61), $t(14) = 196.94$, $p < 0.01$. There were no significant differences between the scrolling and single-line static text displays ($p = 0.27$).

The results here show that participants were better able to adopt the eccentric viewing technique with the RSVP text display (this consistent with the fixation plots) compared to the scrolling and single-line static text display. However, it is important to note that only around 27% of time was spent reading eccentrically. This is expected as the RSVP text display significantly reduces the need to make right and left saccades resulting in participants being able to read eccentrically. On the other hand, participants read eccentrically only 10% of the time with the scrolling text format and this was halved (5%) with the single-line static text display. This indicates the majority of time (90-95%) was spent looking at the text despite there being an artificial scotoma blocking the central field of view. A possible explanation for this may be that participants felt demotivated to read eccentrically due to the difficult nature of the task. However, as observed in the fixation plots there is some evidence of attempting the eccentric viewing strategy by participants and some participants spent longer eccentrically fixating with the scrolling text display. This suggests that there was a sense of willingness for these participants to read and adhere to the eccentric viewing strategy with the scrolling text display but not with the static text display. In this case, participants tended to adopt a different oculomotor behaviour where they made numerous scanning eye movements on the text itself, presumably attempting to sample of the text on either side of the artificial scotoma.

Reading performance analysis

Figure 23

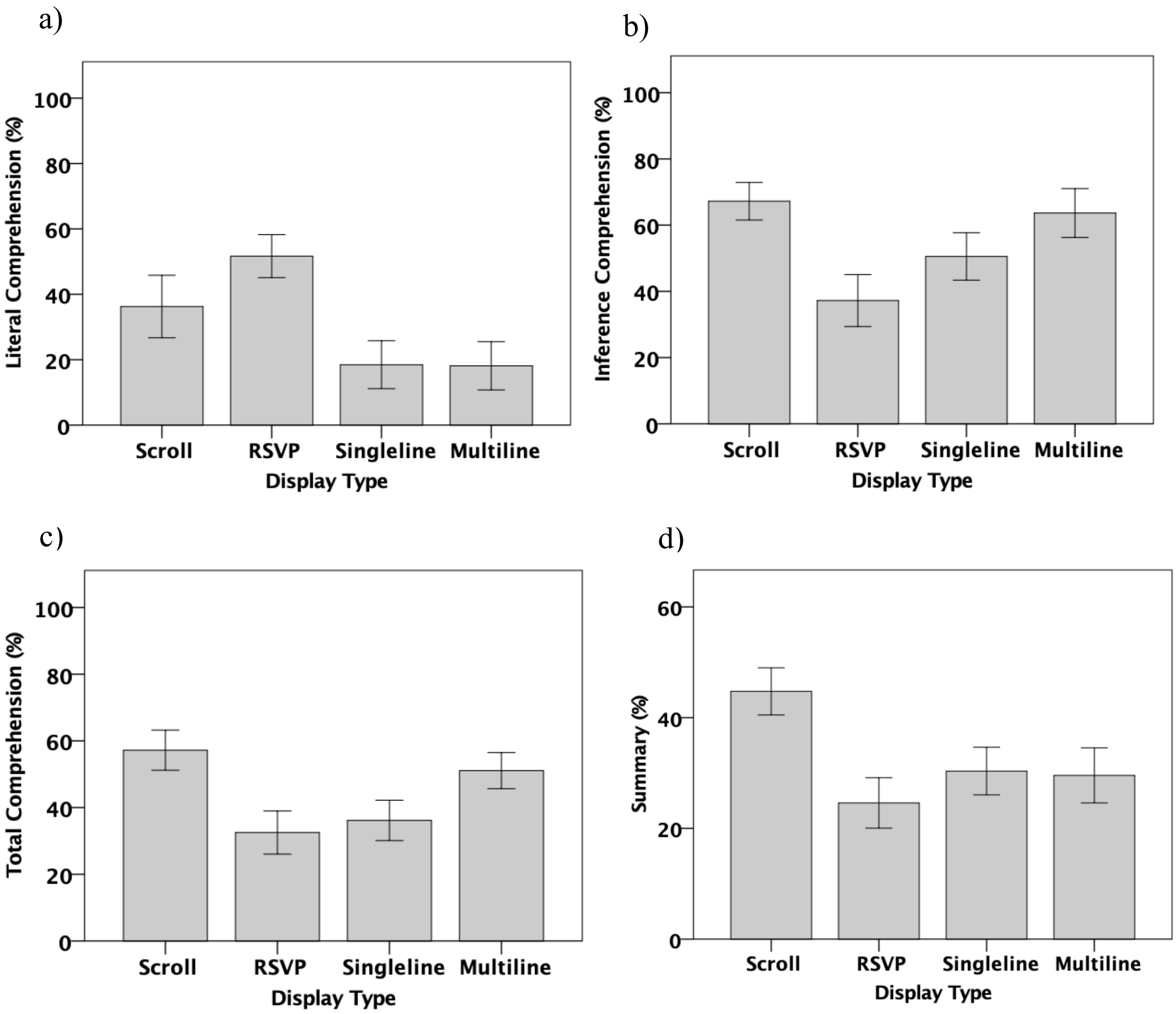
Average number of words read aloud per minute (wpm) for the scrolling text display, RSVP format, single-line static text and multiline static text.



Average reading speed for each condition is shown in Figure 23. A within-subjects one-way ANOVA showed an overall significant effect of text display on reading speed, $F(3, 42) = 5.59$, $p < 0.05$, $\eta^2_G = 0.23$. Participants read the fastest during the multiline text display (M = 163.17wpm, SE = 12.90), followed by the RSVP text display (M = 145.84wpm, SE = 10.08) which was proceeded by the scrolling text display (M = 121.31wpm, SE = 7.35). Reading speed was the slowest during the single-line text display (M = 117.12wpm, SE = 3.84). The pairwise comparison indicated a statistically significant difference between the RSVP and scrolling text display and single-line static text display ($p < 0.001$) and between the multiline and single-line text displays ($p < 0.05$). All other pairwise comparisons were statistically non-significant ($p > 0.05$).

Figure 24

Average percentage of comprehension scores across all of the text display types, a) literal-based comprehension only, b) inferential based comprehension scores only, c) total, overall comprehension scores, d) summary comprehension scores only.



Separate one-way within-subjects ANOVA's and pairwise comparisons were computed to compare comprehension scores (literal and inference comprehension questions and summary scores, as well as the overall total score of all question types) across all four text display conditions (scroll, RSVP, single-line and multiline static text, see Figure 24).

A one-way within-subjects ANOVA indicated a significant effect of display type on literal comprehension (Figure 24a), $F(3,42) = 4.81$, $p < 0.01$, $\eta^2_G = 0.19$. For the literal based scores comprehension was better with the dynamic text displays (RSVP $M = 51.67\%$, $SE = 6.57$, scrolling text display ($M = 36.27\%$, $SE = 9.55$) than the static text displays (single-line static text display, $M = 18.47\%$, $SE = 7.32$, multiline paragraph format, $M = 18.13\%$, $SE = 7.37$). The RSVP text display was better than the single-line static text format, $t(14) = 2.72$, $p < 0.05$ and the multiline paragraph format, $t(14) = 3.09$, $p < 0.01$ as well as the scrolling text display which was better than the single-line static text display $t(14) = 2.11$ and the multiline paragraph format, $t(14) = 2.21$; both $p \leq 0.05$. The pairwise contrasts showed no significant difference between the two dynamic text displays (scrolling and RSVP), $p = 0.26$.

An one-way ANOVA again indicated a statistically significant effect of display type on inferential comprehension (Figure 24b), $F(3,42) = 4.30$, $p = 0.01$, $\eta^2_G = 0.17$. Participants had significantly better inferential scores with the scrolling text display ($M = 67.27\%$, $SE = 5.66$) than the single-line static text ($M = 50.55\%$, $SE = 7.16$), $t(14) = 2.35$, $p < 0.05$ and the RSVP format ($M = 37.22\%$, $SE = 7.84$), $t(14) = 3.07$, $p < 0.01$. The RSVP text display further resulted in significantly worse inferential comprehension than the multiline static text format ($M = 63.65\%$, $SE = 7.37$), $t(14) = 2.37$, $p < 0.05$.

For overall comprehension (Figure 24c), a one-way ANOVA indicated an overall significant effect of display type on the overall reading comprehension, $F(3,42) = 4.56$, $p < 0.01$, $\eta^2_G = 0.17$. The scrolling text display ($M = 57.22\%$, $SE = 6.02$) resulted in better comprehension than the RSVP text display ($M = 32.53\%$, $SE = 6.46$), $t(14) = 53.44$, $p < 0.01$ and single-line static text display ($M = 36.15\%$, $SE = 6.07$), $t(14) = 2.93$, $p = 0.01$. Additionally, the multiline paragraph format ($M = 51.08$, $SE = 5.41$) resulted in significantly better overall comprehension than the single-line static text format, $t(14) = 2.35$, $p < 0.05$.

Finally, there was a significant effect of display type on the percentage of key points successfully recalled by participants (see Figure 24d), $F(3,42) = 5.51$, $p < 0.01$, $\eta^2_G = 0.16$. The highest scores were obtained with the scrolling text display ($M = 44.75\%$, $SE = 4.26$) than the RSVP ($M = 24.59\%$, $SE = 4.55$), $t(14) = 4.83$, $p < 0.001$ and single-line static text display ($M = 30.25\%$, $SE = 4.30$, $t(14) = 3.30$, $p < 0.01$ and the multiline paragraph format ($M = 29.57\%$, $SE = 4.98$), $t(14) = 2.75$, $p < 0.05$.

Reading Accuracy

For the percentage of reading errors (defined as misread, substitutions, insertions and omissions), an within-subjects one-way ANOVA indicated an overall significant effect of display type on error rates $F(3,108) = 1.76$, $p < 0.001$, $\eta^2_G = 0.66$. Reading errors were significantly higher with the RSVP format (M = 49.31%, SE = 8.02) than the scrolling text (M = 1.12%, SE = 0.36), $t(14) = 6.15$, $p < 0.001$; single-line text (M = 1.38%, SE = 0.29), ; $t(14) = 5.96$, $p < 0.001$ and multiline static text (M = 1.51%, SE = 0.26), $t(14) = 5.98$, $p < 0.001$.

Discussion Experiment 1b

Experiment 1b was a replication of Experiment 1a with a similar aims and hypothesis with the main difference being that the speed of dynamic text presentations was matched as close as possible to one another. This was to address a potential speed / accuracy trade-off issue with Experiment 1a where users could adjust the dynamic presentation rate on-line during reading. Here, there was no speed manipulation and speed were matched for both of the dynamic text displays. The guideline for the scrolling text display was also changed from a horizontal line to a cross to allow for better fixation and to match the RSVP text display. In addition, participants were required to read aloud, ensuring that participants were reading the text and to assess reading accuracy. Finally, another difference between experiment 1a and 1b is that in Experiment 1a, a larger font size was used compared to Experiment 1b. An important examination of Experiment 1b was the adherence to the eccentric viewing strategy across the scrolling, RSVP and single-line static text presentations and the oculomotor strategy adopted when reading with this strategy across these text displays and how this affected reading performance. An additional important examination was to assess whether findings from this laboratory-based study with an artificial central scotoma could be generalised to people with an actual loss of central vision (see Chapter 3).

The aim here was to control for reading speed, by setting the rate of scrolling text to be approximately the same as for RSVP and the difference of speed was much closer in Experiment 1b compared to Experiment 1a, although a significant increase was observed with RSVP. Reading comprehension (total comprehension scores) was higher and the number of reading errors lowest with the scrolling text display compared to the other three text displays. This was followed by the multiline static text, where reading comprehension was better than the RSVP and static single-line text display. However, between the two static text displays, participants made more reading errors with the multiline text display compared to the single-line text display. The RSVP display resulted in very poor reading comprehension and a significantly increased number of reading errors compared to all other text display conditions. This appears to be an interesting finding as even though participants were better able to hold their fixation during the RSVP text display, they were poor at comprehending the text, which may reflect known issues with RSVP (Benedetto et al., 2015) and had poor reading accuracy. However, it is important to note the role of speed as a possible factor in comprehension and accuracy as discussed below.

An interesting finding was that reading with the eccentric viewing strategy was challenging and instead participants implemented a different oculomotor strategy going against what the task was even with prompts to encourage participants to adopt the eccentric viewing strategy. However, it is important to note that some participants showed a real attempt of trying to adhere to the eccentric viewing strategy (participants 2, 3, 11, 13). Although participants spent less time eccentrically fixating for instance, participant 3 who spent 28.14% of the time fixating eccentrically with the scrolling text display, the comprehension score was higher than the other participants (scoring a total of 42.86%). There were no significant correlations between the time spent eccentrically viewing (i.e., adopting the eccentric viewing technique) and the overall comprehension score with the scrolling and single-line static text displays, there was a strong negative correlation between the time spent eccentrically viewing and the overall comprehension r_s = -0.704, p = 0.003, N = 15. It is also important to note that participants were better able to adhere to the eccentric viewing strategy with the RSVP text display. In addition, participants scored the highest with the literal comprehension with the RSVP text display, the literal comprehension usually required one or two answer responses and answers were specifically stated in the text. Thus, comprehension will be impaired if participants were not adhering to the eccentric viewing strategy (i.e., looking at the text) as a result of the central scotoma blocking the central field of view.

However, participants attempted to adhere to the eccentric viewing strategy with the scrolling text display (although the adherence was still poor), participants scored higher with the inferential comprehension and gist comprehension (summary key points). The maintenance of eccentric viewing with the scrolling and single-line static text displays appears to be broadly similar with participants making left and right saccades onto the text itself. Although reading comprehension appeared to be better than the scrolling text display. This may be a result of the scrolling text allowing for better peripheral sampling which leads to the possibility of enhancing peripheral acuity when the stimulus is moving at a slower rate (Brown, 1972) thus demonstrating the possible benefits of scrolling text for reading comprehension with central vision loss.

General Discussion

Experiment 1a and 1b investigated reading performance with an artificial CVL, with different text displays (horizontally scrolling, RSVP; static single-line and static paragraph format). Overall, Experiment 1b demonstrated that dynamic text presentation (i.e., scrolling text and RSVP) has the ability to improve and support reading performance (comprehension and accuracy) in people with a loss of central vision. Previous research (e.g. Kang & Mutar, 1989; Fine & Peli, 1995; Rubin & Turano, 1992; Harvey & Walker, 2014) has indicated the possible benefits of using dynamic text such as scrolling text and RSVP text displays (for instance, these formats do not depend on the normal pattern of eye movements and support and aid adherence to holding a PRL) compared to the conventional static text especially for people who suffer from eye disease such as macular degeneration (Harvey & Walker, 2014). Conversely, there has been some reports which have suggested that there is no advantage of this format, showing similar or slower reading speeds with this format than other alternatives (Öquist and Lundin, 2007). However, these studies have focused on reading speed as the main measure for reading performance with a loss of central vision. Here, in these studies reading comprehension (understanding of the text) and reading accuracy (how well the text was read) was measured as well as reading speed, thus giving a richer insight into participants' reading performance.

Previous research suggests that character size is one key parameter which affects reading and the legibility of the text (e.g., Legge et al., 1987; Legge et al., 1989). The character size further reflects the number of saccades and fixations that are made when reading (Chung, 2002). Additionally, although reading with dynamic text and the employment of eccentric viewing comes naturally to people with macular degeneration, due to the majority of sufferers with macular degeneration naturally adopting a PRL, for the majority of young individuals who are normally sighted, this method of reading coupled with a simulated central field loss is unusual. In addition, another key difference between Experiment 1a and 1b was reading silently (Experiment 1a) and reading aloud (1b). Generally reading aloud is related with slower reading and moderately more increase in fixations compared to silent reading (Harvey & Walker, 2014; Rayner, 2009).

The results of Experiment 1b demonstrate that literal comprehension was better with the RSVP than the scrolling and static formats (single-line and multiline formats). It is important to note however, that the majority of literal questions required only a one-word answer, therefore only requiring a single-word recognition (unlike inferential questions where further elaboration and in-depth understanding of the passage was required to answer and score points). RSVP may possibly be a better format for recalling simpler one-word answers rather than for fully comprehending and having a full in-depth understanding of the text. By contrast, inferential, overall comprehension and summary points (measuring gist comprehension, general meaning and understanding of text) were all significantly better with the scrolling text display. Thus, the participants comprehended more of the passage with an in-depth conceptual understanding of the text with the scrolling format. The scrolling text display also resulted in the least number of errors observed, while the RSVP display resulted in the highest number of reading errors.

A major aspect and finding of Experiment 1b were the eye movement behaviour with the different text presentations. The maintenance of holding gaze at an eccentric viewing position was significantly better with the RSVP text display in comparison to static text and as better (but not significantly) than with scrolling text. The improvement in holding an eccentric gaze position with RSVP has not supported improvements in comprehension and this may be due to this format being a poor method of reading as a result of factors such as visual fatigue (Benedetto et al., 2015). Furthermore, participants adherence to maintaining an eccentric viewing position was poor with the single-line static text, which may account for the faster reading speed observed, possibly because they were not reading eccentrically as supported by the low overall comprehension scores. Additionally, the results here may also suggest that participants found it more difficult to implement the strategy of eccentric viewing with static text as reading eccentrically with static text still requires to make eye movements, whereas employing eccentric viewing or steady eye strategy with dynamic text reduces or eliminates the need to make eye movements. The lack of adherence of maintaining eccentric viewing with scrolling text observed in Experiment 1b may be as a result of a lack of practicing to read with scrolling text and a lack of practice of implementing eccentric viewing.

An important goal of Experiment 1b was to balance the rate of presentations of the dynamic text formats (scrolling and RSVP). However, the results indicated a statistically significant difference of reading speed between the two formats – although these were much closer than in Experiment 1a. The presentation and reading speed of RSVP still remained to be faster than the scrolling text display. Previous research has associated RSVP with speed reading, where very fast reading speeds can be achieved (up to 1000 wpm) (Rubin and Turano, 1992). This was supported by Experiment 1a; where reading speed of 183.45 wpm was achieved with RSVP and Experiment 1b where reading speed of 145.84 wpm was achieved. Despite the high reading speed observed in these experiments, the comprehension and reading accuracy remained fairly poor with RSVP.

A further interesting finding relates to literal comprehension, when participants were able to manipulate the speed (Experiment 1a), the literal comprehension was the poorest, however, when RSVP speed was maintained in Experiment 1b, literal comprehension scores were the highest. This may be because there is a trade-off between speed and comprehension where higher levels of speed may result in poorer comprehension, affecting the ability to recall one-word answers and a lower speed may aid comprehension by allowing enough time to comprehend and recall one-word simple answers. Therefore, participants may have selected a speed which was too high to support comprehension. The relatively high reading speed observed with the multiline paragraph format may have been due to the layout being more natural and identifiable for participants, even under the conditions of an artificial scotoma paradigm.

Another possible reason for the poor reading performance observed with RSVP may be due to the level of concentration required to read each word as it is displayed (especially with a central scotoma), a small distraction such as a blink may cause a word to be missed or a distraction which leads to shifting fixation away from the screen will result in missing words, resulting in poorer comprehension. Additionally, other factors reported in previous research such as the suppression of parafoveal processing and regressions have reported to negatively impact on literal comprehension when reading with RSVP (Benedetto et al., 2015). A handful of previous studies have demonstrated that the ability to obtain information from words before directly fixating on them allows to process the word with much more ease once it is fixated upon (Rayner, 2009; Schotter et al., 2012). As RSVP is presented at one word at a time, the role of parafoveal processing is diminished. In addition to this, the presentation of RSVP removes the ability to make regressions, which results in the reader being unable to re-inspect a word if it is missed or mis-read consequently, having a knock-on effect on comprehension. Finally, in these experiments RSVP was presented at a fixed rate (speed was not altered depending on the length of the word) thus, there was no control over the sequence and duration of word processing nor was there control over the oculomotor system which are argued to be important for reading accuracy and comprehension (Benedetto et al., 2015) .

The eye movement analyses showed that participants adhered better to the eccentric viewing strategy with the RSVP text display compared to the scrolling and single-line static text displays. Therefore, the findings of this study did not support the hypotheses that participants will be better able to adhere to the eccentric viewing strategy with the scrolling text display than the static text display. The results further suggested that participants found it challenging to adopt the eccentric viewing strategy even after prompts from the researcher. A small number of participants (specifically, participants 2, 3, 11, 13 and 14) showed some evidence of attempting to adhere to the eccentric viewing strategy. Out of these participants, participant 13 appeared to attempt the eccentric viewing technique exceptionally well, spending 88.4% of the time eccentrically viewing. However, the comprehension score was low (scoring 28.57% overall). Therefore, suggesting that eccentric viewing may compromise reading comprehension. There are a few possible reasons why this may have happened. Firstly, attempting to change the natural oculomotor behaviour (in this case adopting the eccentric viewing technique by fixating above the text and attempting to read below) may have been too difficult to do or for some participants impossible to do. Although some participants did try and attempt this, they reverted back to looking at the text regardless of the 8-degree scotoma blocking the view. Instead, participants shifted their eyes to the right or left to see the text, which was a closer technique to the natural way of reading with normal vision. The speculation here is that participants may have not been able to overcome or inhibit the natural strong eye movement behaviour. This can be related back to the case study of AI who was an individual diagnosed with congenital, extraocular muscular fibrosis which led to ophthalmoplegia. AI was unable to make eye movements and thus compensated by making head movements when reading. AI's head movements showed that saccades are a natural tendency (Buchardt et al., 1997) and thus, the participants in Experiment 1b were unlikely to deviate from the natural oculomotor tendency and adopt a new strategy especially in the short time of this experiment. The eye movement analyses showed and supports the view that it is exceptionally difficult to overcome the deep routed eye movement behaviour response and reflex especially with normal vision.

The eye movement analyses of the number and amplitude of saccades indicated that participants made more saccades horizontally rather than vertically. This indicated that participants were moving their eyes left and right rather than up and down. In addition, with the single-line static text display, more saccades were made to the left compared to the scrolling text display, a possible reason for this may be that participants may be looking at the text and making horizontal eye movements to move the scotoma to the right and attempting to read the text to the left using their peripheral vision rather than adopting the eccentric viewing strategy (fixating above and attempting to read below). Significantly fewer leftward saccades were made with scrolling text was and this may be attributed to the limited opportunity for regressive saccades with this format as it scrolls off the display screen. The greater number of saccades to the right observed with the scrolling text is consistent with findings by Rubin (2001) where participants read with a 3.5 ^{o} artificial scotoma. It was suggested by Rubin (2001) that participants had adapted their eye position samples to the right when reading compared to when they were reading with static text with the absence of a scotoma. Therefore, participants had moved their gaze slightly and used a region in the left visual field to help them to read the text. This further suggests that the left-right scanning technique (similar to this experiment) may reflect a possible strategy used by participants to attempt to view and process the text to the left and right of the scotoma. It was reported that the eye movement behaviour was disorganised with a greater number of fixations and smaller saccades within words (Rubin, 2001). In line with Rubin's (2001) study, there were also more saccades which were made to the right as well as a greater saccade amplitude to the right. It is also important to note that previous research also stated that patients diagnosed with macular degeneration made patterns of forward and backwards saccades when reading static text thus consistent with the findings here (it was observed participants were moving their eyes left and right), although here participants were reading with an artificial scotoma (Legge, Ross, Luebker, et al., 1989).

Therefore, participants who have normal vision reading with an artificial scotoma seem to revert back to the typical eye movement behaviour when reading with some attempt in trying to adopt the eccentric viewing technique which may be as a result of the lack of ability to overcome the typical eye movement pattern whilst reading. This reinforces the strong overlearned behaviour of the eye movement system.

Nevertheless, the present study supports previous research (Calabrèse et al., 2014; Harland et al., 1998; Harvey & Walker, 2014; Legge et al., 1985; Legge, Ross, Maxwell, et al., 1989; Walker, 2013; Walker et al., 2016) that has shown the possible advantages of adopting horizontally scrolling text display formats compared to static text with regards to reading comprehension and accuracy (Harvey & Walker, 2014). The findings of this study show that the overall reading performance (reading accuracy and overall comprehension) was better than other forms of text presentation. The scrolling text display results within the present study are consistent with Harvey & Walker (2014), which also implemented an artificial scotoma paradigm. The improvement in reading comprehension within this text display resulted in making less reading errors (Harvey & Walker, 2014). Moreover, this study supports previous research which found that the ability to retain information was the poorest in the RSVP text display compared to other techniques such as rapid skimming at a rate of 600 wpm (Potter et al., 1980). Although RSVP is the fastest in terms of text presentation, reading comprehension with the RSVP text display was the poorest which is consistent with previous work showing this to be a poor method of reading (Benedetto et al., 2015). In addition, the eccentric viewing technique (requiring adopting a different oculomotor strategy) is extremely challenging for people with normal vision to adopt as a result of their natural strong tendency to direct gaze on the text (natural eye movement behaviour).

Chapter 3.

Reading comprehension, with static and dynamic text in participants with macular degeneration and a central vision loss.

Introduction

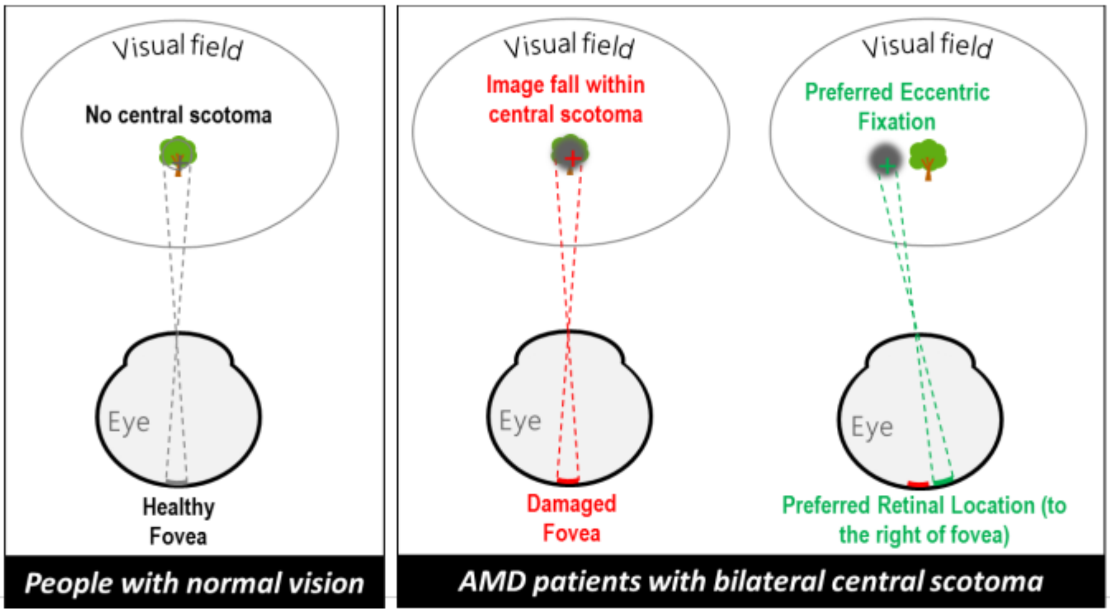
The use of peripheral vision, magnification and reading strategies such as steady-eye strategy and eccentric viewing are commonly used in low vision clinics as methods of rehabilitation for those diagnosed with visual disease such as macular degeneration (Reeves et al., 2004). The steady eye technique, which may be used in conjunction with the eccentric viewing strategy, involves the reader to keep the eyes fixated at a particular region and moving the text from right to left through the intact remaining region of the retina (Watson & Berg, 1983). The eccentric viewing strategy is also used by those with CVL for tasks such as reading. The damaged central area of vision results in the adoption of the areas of the retina which are preserved; peripheral regions where visual acuity is compromised and significantly reduced and unaffected by the disease. These reading strategies are particularly beneficial with dynamic text presentations such as horizontally scrolling text and RSVP (where one word is presented one at a time in sequential order). With horizontally scrolling text, the text is able to move smoothy across the retina whilst the eccentric viewing strategy is adopted (Harvey & Walker, 2014) thus, altering the normal oculomotor pattern and reducing the demands of the oculomotor system thus supporting reading with a loss of central vision (Bernard et al., 2007; Bowers et al., 2004; Fine & Peli, 1995b; Harvey & Walker, 2014; Lingnau et al., 2008; Rubin & Turano, 1994). The typical oculomotor behaviour when reading with scrolling text are intervals of smooth pursuit; a slow tracking movement used to stabilise the retinal motion as a result of a moving stimulus. This pattern substitutes the fixation intervals with conventional static text. Reading with scrolling text is advantageous as it can decrease blurring of the stimulus across the retinal image (Krauzlis, 2004; Robinson, 1965) thus potentially increasing reading performance (comprehension and accuracy) (Walker et al., 2016). On the other hand, with the RSVP text display, the need to make eye is considerably reduced allowing to implement strategies such as the steady eye strategy. There has been some evidence of reading with RSVP reducing the necessity of making saccadic eye movements resulting in a faster reading rate (Sharmin et al., 2012) as well as using the PRL more efficiently.

The primary aim of people with CVL (75%) attending low vision clinics is to seek help to ameliorate their reading impairment (Elliott et al., 1997). As a result, reading is regarded as the most important rehabilitation aim of patients with low vision (Elliott et al., 1997). For individuals who have low vision and CVL as a result of macular degeneration, the maximal reading speed is considerably slower, typically below 100 wpm or in severe cases 10 – 20 wpm (Legge, Ross, Maxwell, et al., 1989). This slow reading speed is thought to arise from the increase in the number of regressive eye movements required to re-inspect the text, less letters being perceived per forward saccade and a decline of visual span (Legge, Rubin, Pelli & Schleske, 1985). The amount of time it takes to read is also dependent upon the number and duration of fixations made onto the text. If the average length of saccades is shorter and the number of fixations are greater, then this would result in a slower reading rate. This is consistent with eye movement studies that have found that subjects with low vision tend to make smaller saccades compared to those individuals who are normally sighted (Bullimore & Bailey, 1995).

In order to facilitate tasks such as reading the majority of individuals who have acquired CVL may adopt an eccentric retinal region in order to hold their best region of non-foveal region (and vision) onto the stimulus to be recognised (von Noorden & Mackensen, 1962). This is termed a PRL or *Pseudo-fovea,* and is commonly adopted either naturally, or through guidance and training (Cummings et al., 1985; Timberlake et al., 1986). The PRL is ideally located in the region of the remaining unimpaired retina that has the best visual acuity (see Figure 25 below). Fletcher & Schuchard (1997) found that 80% of patients diagnosed with AMD adopted an eccentric PRL when carrying out visual tasks such as reading. The use of a PRL is motivated by the need to improve visual acuity and for a functional adjustment with the goal of decreasing the consequences of the scotoma on central visual fields (Fletcher and Schuchard, 1997). The individual must achieve smooth pursuit (to help aid with navigation of text as a result of the inability to hold steady eye consistently) and saccadic movements through this retinal location as a guide (Schuchard et al., 1994; Schuchard & Fletcher, 2000) to facilitate discrimination of fine detail necessary for reading (Deruaz et al., 2002). However, it is important to note that more than one extrafoveal locations can be implemented by individuals within and between visual tasks. During reading, for example, employing one PRL may be used to obtain a global view of the text and another PRL to distinguish between one or two letters more accurately (Duret et al., 1999; Kanonidou, 2011; Sunness et al., 1996). Additionally, the location of the PRL is important for text navigation. Watson et al., (2006) found significant differences between the location of the PRL and scotoma on text navigation, where a PRL located to the left, or above the scotoma resulted in a reduction of text navigation. In addition, those who placed the PRL to the left of the scotoma resulted in words which had similar beginnings being misread and the last word on a line being omitted. Patients who placed the PRL above the scotoma often skipped a line or re-read the same line a number of times.

Figure 25

Schematic diagram of normal vision (left), a damaged fovea resulting in a central scotoma (middle) and eccentric viewing and the preferred retinal locus (right). The preferred retinal locus is the area which provides the best vision when the fovea is impaired (Yow et al., 2018).



Reading with dynamic text presentation and a central vision loss

The use of modern technology coupled with dynamic text presentation such as RSVP and horizontally scrolling text has been investigated with the aim of improving reading performance in people with a loss of central vision. RSVP involves each word being displayed in sequential order at the same location. Horizontally scrolling text (also termed as drifting, leading, or Times Square format), refers to a single line of text which scrolls horizontally from right-to-left text in a smooth pixel formation. The majority of people with a loss of central vision have a low reading speed and possess many challenges when reading conventional static text. For instance, reading with static text may result in difficulties with navigation especially with multiple lines of static text (Deruaz et al., 2002). Another difficulty with static text is crowding; the inability to distinguish individual objects when they are spatially too close to other nearby objects (Whitney & Levi, 2011; Zahabi & Arguin, 2014). These factors as well as poor oculomotor control (White & Bedell, 1990; Whittaker et al., 1991) may be reduced with dynamic text presentation.

The use of dynamic texts formats, such as RSVP and horizontally scrolling text may help control for aberrant patterns of oculomotor behaviour. It has been shown for example that scrolling text encourages and increases reading performance (Kang & Muter, 1988) and an increased memory that is also sustained at higher reading speeds. There is also a subjective preference for reading with scrolling text over RSVP as a reading aid for people with low vision (Lin & Shieh, 2006). However, a major advantage of both types of dynamic text presentations is the reduction in eye movements required and the ease at which steady gaze positions can be held to read text displayed as RSVP and scrolling text thus being particularly beneficial for individuals with CVL (Harvey & Walker, 2014; Rubin & Turano, 1994). Reading with dynamic text formats results in reading strategies such as eccentric viewing and steady eye strategy to be adopted much more easily, enhancing reading speed (Fine & Peli, 1995).

Bowers, Woods & Peli (2004) assessed the association between the position of the PRL and reading rate with four dynamic text presentations which included; RSVP, horizontal scroll, vertical scroll and static paragraph format (PAGE) text with subjects who had low-vision whom the majority had CVL and an age-matched control group. This was to examine the effects of the position of the PRL on different dynamic text displays on reading speed with this population. The results indicated no significant differences with regards to the position of the PRL on reading rate for all of the text display formats investigated, thus whether the scrolling text was presented vertically or horizontally did not affect where the participant located their PRL. This finding was also supported by Fletcher & Schuchard (1997) whereby the maximum oral reading rate with multiline text, in participants with macular degeneration, was not influenced by the PRL position. It has been reported that the location of the PRL can be established in all regions and/or directions around the scotoma. However, the development of a PRL may potentially take up to 6 months and different locations of the PRL may be adopted by people with central scotomas for different tasks (reading, watching tv, driving etc.) (Crossland et al., 2005). In another study it was found that in people with scotomas, there was a strong tendency of the human visual system to avoid placing the PRL anatomically above the scotoma (i.e., the field defect below fixation) or to the right of the scotoma (i.e., field defect to the left of fixation) (D. C. Fletcher & Schuchard, 1997).

Previous research has suggested that the position of the PRL (which may be influenced by the size and shape of the scotoma) is an important element for establishing reading speed with the conventional, static text such as the static paragraph text display

(Bowers et al., 2004; Fine & Rubin, 1999; Petre et al., 2000; Rayner et al., 1980). Furthermore, participants with macular degeneration showed an increase reading rate when the text was read silently in multiline format compared to the other display types. However, the majority of the low vision groups expressed a preference for reading with the horizontal scrolling text format compared to all the other text displays, despite the lack of difference in performance, and only a small minority preferred reading with the RSVP text display (Bower et al., 2004). This finding was also supported by Harland, Legge & Luebker (1998) where subjects reported a preference of reading with the horizontally scrolling text in comparison to RSVP.

The majority of studies focusing on dynamic text presentation with individuals who acquire a loss of central vision have tended to focus on reading rate as the main measure of reading performance and very little on reading comprehension. However, in a study conducted by Legge, Ross, Maxwell & Leubker (1989) reading comprehension and speed were examined with both individuals who were normally sighted and individuals with low vision. The results showed that in the case for people who were normally sighted reading comprehension moderately declined from 71.2% to 60.5% as the scrolling text speed increased from 10 to 200 wpm; further increases in scrolling speed produced a faster decline in comprehension. In addition, comprehension did not decrease for scrolling speeds of less than 100 wpm, but instead increased slightly at 10 and 30 wpm. This supports the idea that individuals can comprehend text which is read at slower rates as well as faster rates.

These findings are promising as they suggest that good comprehension is attainable even at low reading rates with scrolling text. Legge et al., (1989) measured the association between oral reading rate and scrolling speed at which reading comprehension is unsuccessful. The results indicated a weak relationship whereby comprehension was unsuccessful when individuals who were normally sighted read approximately around 70% (230 versus 320 wpm) of their highest reading rates. Additionally, when comparing scrolling text with the conventional static text on paper, it was found that individuals can understand text that scrolls at the same rate to their normal reading rate. For the group with low vision, comprehension with oral reading at two different scrolling speeds were measured, the faster scrolling speed averaged 84% of the oral reading rate and the slower reading rate at an average of 67%. The results also indicated slightly better reading comprehension scores with a slower scrolling speed with an average of 64% of correct scores compared to the faster scrolling speed with an average of 60% of scores correct. These averages appeared to be moderately less than the average comprehension scores observed with the individuals who are normally sighted with the same scrolling speed. Additionally, for both of the scrolling speeds, the majority of individuals with low vision obtained comprehension scores close to the average observed with individuals who were normally sighted. Furthermore, a group of individuals with low vision achieved a comprehension score which was higher than the normal average for individuals who are typically sighted. The lower comprehension scores observed with the low vision group may be due to demographic differences (e.g., age differences) however overall, the results are encouraging for this group who were able to achieve a good comprehension at slow reading speeds (Legge et al., 1989).

The reading rate of people with CVL can vary depending on the text presentation method used and this may be attributed to differences in the oculomotor behaviour used. Rubin & Turano (1994) investigated reading speed with individuals who have a loss of central vision by examining oculomotor control with the RSVP text display and comparing this to the conventional static paragraph format. It was found that with RSVP, reading rates (in wpm) of people with CVL significantly increased as a result of the need to make less saccadic eye movements during the RSVP text compared to the static paragraph format. However, although a decrease of saccadic eye movements was observed, those with CVL needed longer word durations compared to individuals with no CVL. Rubin & Turano (1992) further concluded that these results demonstrate that disorganised oculomotor control is responsible for only a small portion of the increased reading rate observed in people with CVL and instead visual and cognitive processing factors for reading may play an important role. Additionally, the average speed for text with an 8X acuity (intermediate letter size) was 1171 wpm with the RSVP text display compared to 303 wpm with the static paragraph format. Rubin & Turano (1992) also found that the majority of people who were normally sighted read faster with the RSVP text display, six of the participants managed to read at the maximal testable rate in the study which was 1652 wpm, scoring a minimum of 75% correct on the reading comprehension tests. Thus, it is evident that RSVP has the potential to improve reading speed compared to the conventional static text (Rubin & Turano, 1992).

There are, however, some differences between those individuals with CVL and people with normal vision with regards to reading rate with RSVP even when identical retinal eccentricities are adopted by all participants. Reading rate appears to be much slower for people with CVL than people who are normally sighted (Rubin & Turano, 1994). Rubin & Turano (1994) proposed that there must be additional factors (such as exploring the reduced ability of the peripheral retina to phase information; the determination of the relative locations of spatial frequency (Rentschler & Treutwein, 1985), along with a decline of saccade length which contribute to the lower reading rates observed in those with CVL. This was consistent with a study conducted by Raasch & Rubin (1993) who proposed that the quality of visual functioning, which outlines the outermost edge of the scotoma, is a determinant of the reduction in reading rate observed in those with low vision. Conversely, it was argued that the lack of oculomotor control was a more dominant characteristic of the slow reading rate than the unstable eccentric fixation observed in those with low vision (Timberlake et al., 1986). Research on the different components of the reading processes has found that reading rate is particularly sensitive to changes in an individual's visual processing or the characteristics of print (Whittaker & Lovie-Kitchin, 1993). Four key visual factors thought to have an impact upon reading rate are acuity reserve, contrast reserve, field of view and central scotoma size. Whittaker & Lovie-Kitchin (1993) found that with a restricted field of view, fluent reading rates can be achieved. Despite this, the achievement of fluent reading is dependent upon the print size and contrast being several times above threshold and the central scotoma should be no more than 22 degrees. In order to assess the role of print size on reading rate at various eccentricities in normal peripheral vision, Chung, Mansfield & Legge (1997) measured reading rate with an RSVP display, for eight different print sizes present at size retinal eccentricities. The eccentricities started from zero (i.e., foveal) to 20 degrees in the inferior visual field. The results determined that for the peripheral vision an increased print size is necessary to obtain the maximal reading in comparison to the central vision. Furthermore, the time at which reading speed alters as a function of print size, appeared to remain proportional in both the central and peripheral vision regardless of whether the print size is the limiting factor, the reading rate using the peripheral vision is considerably reduced than that observed in the central vision (Chung, Mansfield & Legge, 1997).

Studies have investigated some of the visual characteristics which can aid reading using RSVP. Fine & Peli (1998) examined reading speed in people with low vision with RSVP and scrolling text at different letter sizes based upon participants' acuity to assess the benefits of RSVP. Furthermore, Fine & Peli (1998) aimed to investigate whether acuity reserve is a feasible metric to adopt in determining reading performance. The results indicated that the individuals with low vision read on average faster with the RSVP text display compared to the scrolling text display when the text size was bigger comparative to their maximal acuity. However, the readers who read at their maximal speed with a smaller text size, read more rapidly from both the RSVP and scrolling text displays, thus supporting findings by Rubin & Turano (1994) who also found that large letter sizes to obtain maximal reading rates resulted in a decrease in reading rate. Additionally, Fine & Peli (1998) further combined data from a previous study (Fine & Peli 1995; Fine & Peli, 1996) where only one letter size was used to compare reading rate with scrolling and RSVP text displays. They found that some participants (59%) increased their reading rate by 10% with the scrolling text display, while 32% had a 10% increase of reading rate with the RSVP text display (Fine & Peli, 1998). The participants with low vision showed no advantages of reading with the RSVP text display until the text size was 8x their acuity threshold, for 25% of participants, the reading rate was increased when reading with the scrolling text display than the RSVP text display.

The majority of studies investigating the potential of dynamic text displays with both scrolling text and RSVP, have tended to focus on reading speed as the main measure of reading performance in people with central vision loss. However, as noted previously, reading speed may not be the optimal measure as this depends on the rate of text presentation that imposes the maximum reading speed. It may also not be appropriate to set the same rates of presentation due to the very different oculomotor strategies involved in reading with single word RSVP and scrolling text. Reading comprehension by contrast, gives a useful measure which demonstrates the extent at which the individual has understood the material being read (the ultimate goal of reading) that does not directly relate to rate of presentation. Further examination of reading performance, in people with a loss of central vision, with dynamic text formats is important as they may potentially be adopted as reading aids for this population by overcoming the challenges found with static text.

This study builds upon the previous experiments (Experiment 1b, Chapter 2) that applied an artificial scotoma paradigm in a laboratory setting, by testing a sample of participants with a diagnosis of macular degeneration and a CVL. The aim is to examine reading performance (specifically comprehension and accuracy) with dynamic and static text formats, presented on an iPad tablet, which can be a useful accessibility tool for readers who are visually impaired. This will allow a direct comparison of reading performance, with different methods of text presentation using the same screen. It will also show if performance from a laboratory simulation study can be generalised to elderly people with an actual CVL. It is hypothesised that participants will have better reading performance (comprehension and accuracy) with the scrolling text display compared to the RSVP and static text presentations, thus being consistent with findings of Experiment 1b. In addition to this, this study will examine whether findings from a laboratory-based study (Experiment 1b, Chapter 2) with an artificial scotoma. Additionally, studies of reading performance from the laboratory-based experiments using an artificial scotoma paradigm will be generalisable to reading performance of people with CVL as a result of macular degeneration.

Method

Participants

A total of thirty-seven participants (female = 32) with a diagnosis of macular degeneration (mean age = 77.54 years; *SD* = 10.89, mean years since diagnosis = 8.68, *SD* = 5.14 - see Table 2) were recruited from the membership of the Macular Society (UK) via their e-newsletter. Near distance visual acuity (measured using the MNREAD near distance visual acuity test) ranged from 1.42 to -0.18 logMAR (mean logMAR = 0.58, *SD* = 0.40). The distance binocular reading acuity was obtained using the Bailey-Lovie Visual Acuity chart) (Bailey & Lovie, 1976) (mean logMAR= 0.86, *SD* = 0.35). All of the participants were located within a 40-mile radius of Royal Holloway, University of London (RHUL), Central London and Cambridgeshire. All participants spoke British English as their primary language and were within the normal (unimpaired) range on the Six-item Cognitive Impairment Test (6CIT - Kingshill Version 2000, Dementia screening tool, see Appendix 3). The inclusion criteria to take part within the study consisted of; a diagnosis of macular degeneration (wet, dry or both, or other forms of MD such as Stargardt disease), with a confirmed central vision loss in at least one eye, and English as the primary language. The exclusion criteria consisted of; other ocular comorbidities and any language, reading or cognitive impairment (see Table 2 for participant information and diagnoses). All participants gave verbal consent and written informed consent prior to participating within the study. The study was reviewed and approved by the College Ethics Committee at Royal Holloway, University of London (Ethics ID 2017/633), and were carried out in line with the tenets of the Declaration of Helsinki (see Appendix 1).

Table 2

Clinical characteristics of participants with macular degeneration including age, gender, self-reported diagnosis, reading acuity (logMAR), distance visual acuity (logMAR) and years since diagnosed.

ID	Age	Gender	Diagnosis	logMAR (Reading Acuity)	Distance Visual Acuity (logMAR)	Diagnosed (years)
1	73	F	Both eyes Dry AMD, CVL in RE	0.64	0.72	9
2	78	F	Both eyes Wet AMD, CVL in both eyes	0.59	0.74	7
3	83	M	Both eyes Dry AMD, CVL in both eyes	0.21	0.78	28
4	82	F	Both eyes Dry AMD, CVL in both eyes	1.22	1.46	9
5	87	M	Both eyes Wet AMD, with CVL in LED	0.17	0.96	8
6	76	F	Wet in LE with CVL, Dry AMD in RE	0.52	0.62	5
7	85	M	Dry AMD in LE, Wet AMD in RE with CVL	0.9	1.32	12
8	81	F	Both eyes Dry AMD, CVL in both eyes	-0.18	0.48	6
9	77	F		1.06	0.52	12

			Both eyes Dry AMD, CVL in both eyes			
10	82	F	Both eyes Wet AMD, CVL LE	0.90	0.82	6
11	85	F	Both eyes Wet AMD, CVL in both eyes	0.62	1.22	11
12	64	F	Both eyes Wet AMD, CVL in RE	0.7	1.12	5
13	73	F	Both eyes Dry AMD, CVL in LE	0.46	0.42	5
14	78	F	Both eyes Dry AMD, CVL in RE	0.94	1.04	7
15	36	M	Stargardt Disease	1.06	1.42	7
16	46	M	Stargardt Disease	0.75	1.28	6
17	87	F	Both eyes Wet AMD, CVL in both eyes	-0.18	0.52	9
18	78	F	Both eyes Dry AMD, CVL in RE	0.1	0.34	7
19	65	F	Wet AMD in LE with CVL, Dry AMD in RE	0.3	0.70	4
20	74	F	Both eyes Dry AMD with CVL in LE	0.73	0.26	5
21	82	F	Both Eyes Wet AMD with CVL in RE	0.1	0.82	7

22	73	F	Both Eyes Wet AMD with CVL in LE	0.17	0.42	8
23	95	F	Both Eyes Dry AMD with CVL in LE	1.26	1.48	19
24	79	F	Both Eyes Dry AMD with CVL in RE	0.19	1.12	9
25	87	F	Both Eyes Wet AMD with CVL in RE	-0.09	0.32	14
26	74	F	Both Eyes Dry AMD with CVL in LE	1.09	1.12	6
27	79	F	Both Eyes Wet AMD with CVL in RE	1.15	1.12	10
28	78	F	Both Eyes Dry AMD with CVL in RE	1.06	1.42	6
29	80	F	Dry AMD in RE and wet AMD in LE, with CVL in both eyes	0.51	0.70	2
30	77	F	Both Eyes Dry AMD with CVL in RE	0.48	0.52	2
31	85	F	Both Eyes Dry AMD with CVL in LE	0.78	1.20	10
32	88	F	Both Eyes Wet AMD with CVL	0.31	0.72	7
33	84	F	Both Eyes Dry AMD with CVL in LE	0.88	0.92	5

34	76	F	Both Eyes Dry AMD with CVL in RE	0.45	0.92	22
35	74	F	Both Eyes Dry AMD with CVL in RE	0.26	0.72	8
36	82	F	Both Eyes Wet AMD with CVL	0.59	0.72	10
37	86	F	Both Eyes Wet AMD with CVL	0.78	0.72	8

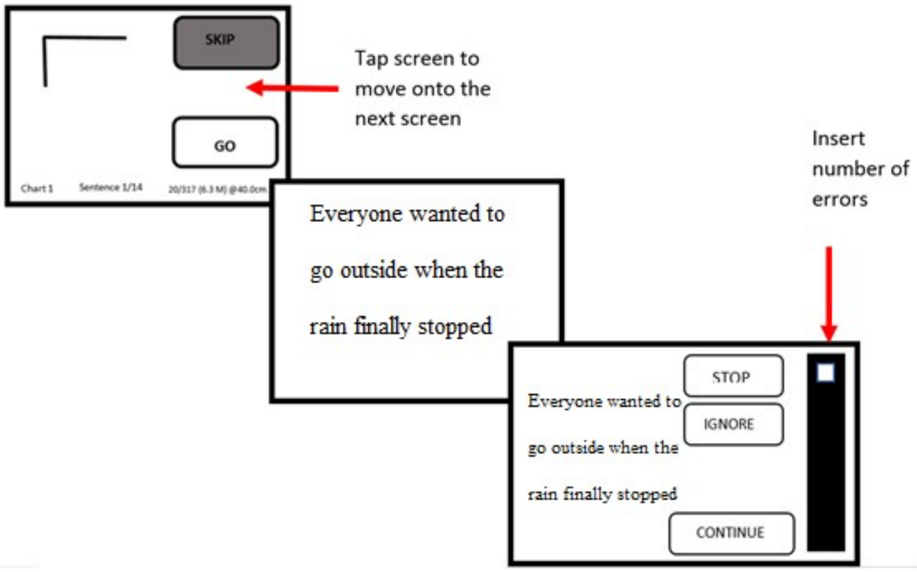
Clinical measures

All clinical measures except the Bailey-Lovie Visual Acuity Chart were administered on a 9.7inch iPad 2 (iOS 11.3.1) retina display. The Bailey-Lovie Distance Visual Acuity Chart (WxH = 56 cm x 65 cm) was measured at a distance of 1-3 metres and the logMAR was corrected accordingly for calculation. The chart consisted of 5 letters per row starting from 0.8 logMAR with the letters decreasing in size to -0.5 logMAR. The digital version of the MNREAD near distance visual acuity charts (Legge, 1997) (see Figure 26) was used to measure reading acuity at a short distance, critical print size (CPS), maximum reading speed and the reading accessibility index. All of the sentences were presented in 'Times New Roman' font (evenly spaced), in black on a white background. The sentences were presented on a 75% brightness level (200cd / m2) in an evenly illuminated room, at a distance of 20-40 cm (recommended values of viewing distance for people with low vision). Each MNREAD sentence contains 60 characters (including spaces), 14 sentences (e.g., "Everyone wanted to go outside when the rain finally stopped") with the print reducing in size by 0.1 logMAR, and the print sizes varying from 6.3 M to 0.32 M (in Sloan M notation) or 9.3 mm to 0.5 mm (in x-height). Before beginning the MNREAD test, participants completed a practice trial to ensure they were comfortable with what the test entailed. The practice trial took around 5 minutes on average to complete. The MNREAD chart took around 15-20 minutes on average to complete. All tests were administered binocularly including the reading of passages.

Participants were screened for cognitive deficits using the Six-item Cognitive Impairment Test (6CIT - Kingshill Version 2000, Dementia screening tool) was conducted before the study to detect any mild cognitive deficits (see Appendix 3).

Figure 26

Schematic diagram of the procedure used for the digital MNREAD visual acuity chart.



Reading Assessment

The Primary YARC (Hulme, Stothard, Clarke, Bowyer-Crane, Harrington, Truelove and Snowling, 2009) were used (see Table 3) to test reading performance. The primary YARC passages (see Appendix 4 for full passages) consist of questions split into literal based and inference-based comprehension questions. The questions were presented in paper format, were read out loud to the participant, and given straight after they had finished reading the passage. All of the text passages were counterbalanced between participants. However, the scrolling text presentation was always given before the RSVP text presentation. This was to ensure that an accurate speed could be set and presented as it is evident through piloting the study that the RSVP text display can be read faster than the scrolling text display. Participants were given a practice trial before reading the actual passage, this consisted of different sections of the news (116 -120 words) taken from BBC News.

Table 3

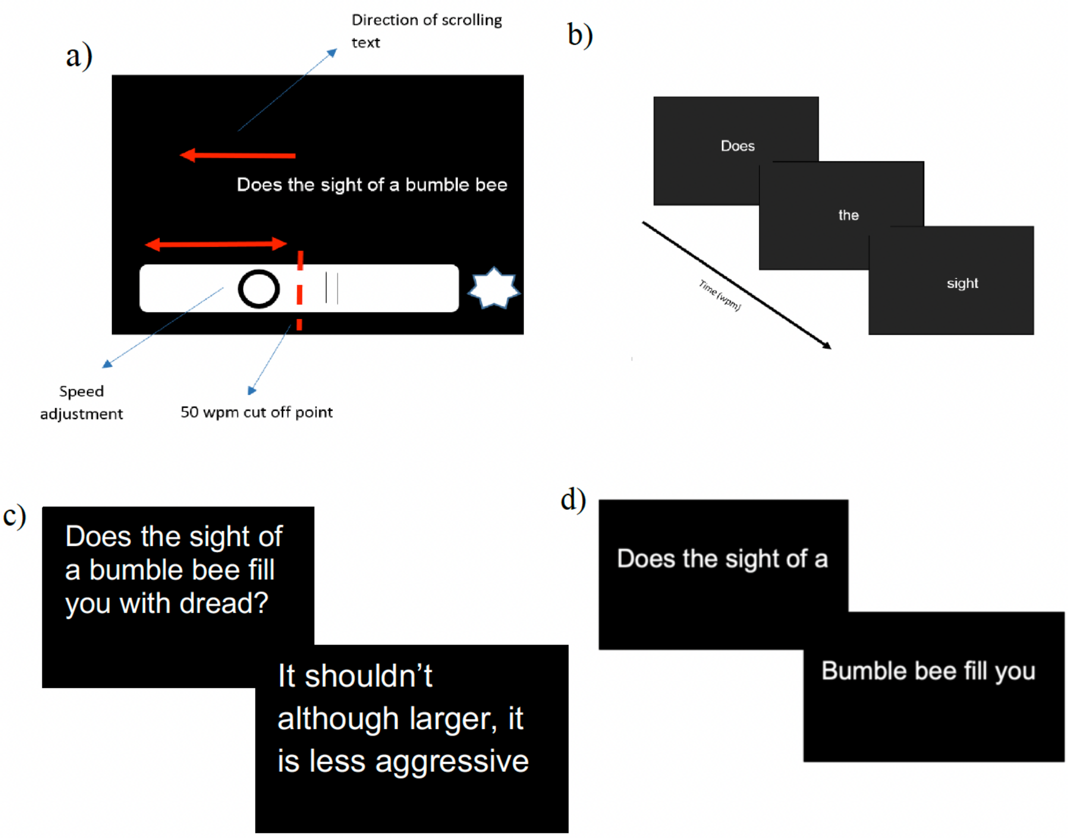
The total number of scores available for the literal and inference sections of the comprehension test, the total number of scores available overall and the total number of sentences within each passage of text (Stothard et al., 2009).

Passage of text	Literal	Inference	Total available score	Total number of sentences
Bees	4	3	7	9
Pirates	2	6	8	10
Reptiles	4	4	8	9
Shoes	5	3	8	11

Horizontally scrolling text was presented using the 'MD_evReader' application (Walker 2013). This application allows text to be scrolled horizontally in a single line across the iPad screen (like a news ticker) (see Figure 27a). The RSVP format (see Figure 27b) was displayed on a on a Samsung Galaxy Tab E (9.7-inch display) using a custom-coded Android application (designed in-house for this study at Royal Holloway, University of London). The static (single-line and multiline paragraph, see Figures 27c and d) text displays were presented using PowerPoint on an iPad. All passages of text with all text displays were presented in Arial font in white on a black background.

Figure 27

Schematic diagrams of the text displays (a) the scrolling text display showing the direction of text, the 50 wpm cut off point and the slide bar used to adjust the speed, (b) the RSVP text display, (c) multiline text display, (d) the single-line text-display.



Design

All participants successfully completed reading (aloud) with all four text displays (scrolling, RSVP, single-line and multiline) including answering the comprehension questions and clinical measures (MNREAD Visual Acuity Chart and the Bailey-Lovie Distance Visual Acuity Chart). The comprehension questions were scored as the percentage of correct inference-based questions and literal based questions and overall total. Reading errors were categorised as the percentage of words that were missed, substituted or read incorrectly whilst reading the passage. These errors were converted into an overall percentage for each text display type.

Procedure

All participants first underwent a telephone screening questionnaire and a demographic questionnaire to ensure that the eligibility criteria were met (see Appendix 2). Participants were visited in their own home and all gave written informed consent prior to taking part in the study. All participants completed a 'Six Item Cognitive Impairment Test' (6CIT), Kingshill Version 2000, which is a dementia screening tool. This took around 5 minutes in total to complete. The MNREAD chart was the first visual assessment tool completed, this was tested binocularly, at a distance the participant felt comfortable reading at. The MNREAD visual acuity chart was presented digitally on an iPad ensuring it was presented at eye-level. Once the distance was set, participants were instructed not to move so the distance remained approximately constant. The distance from the participants eye to the iPad screen was measured. The participants were asked to read each sentence aloud until they could no longer read anymore. All errors were recorded to ensure an accurate near distance visual acuity was obtained.

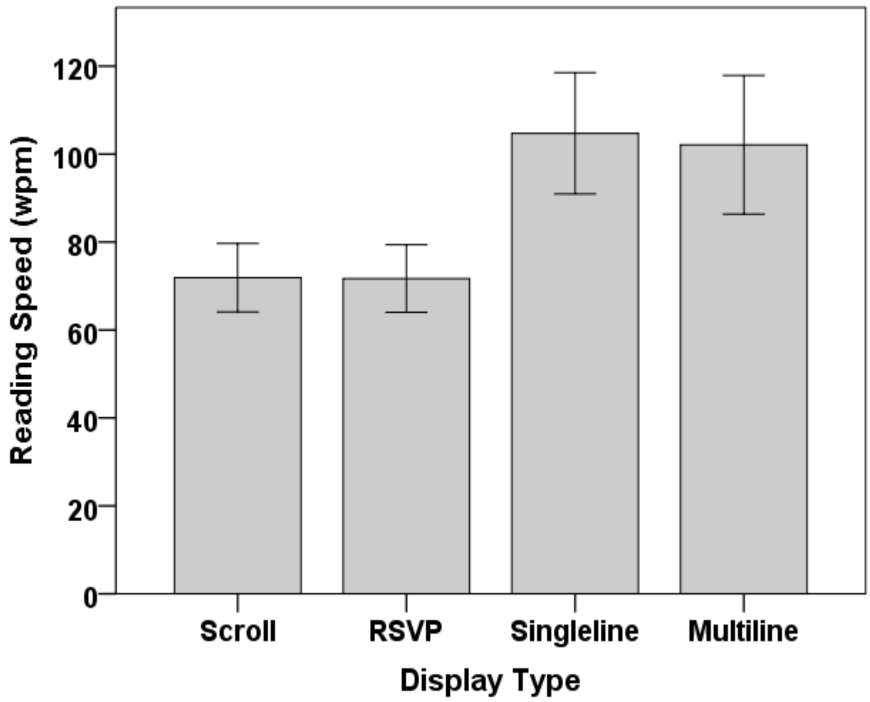
After completing the MNREAD visual acuity chart, the CPS was calculated automatically through the application. The participants critical print size x2 was used as the font size for each text display (horizontally scrolling text display, RSVP text display and the static (single-line and multiline) to ensure a comfortable size to reduce eye strain (based on a separate pilot run). The text displays were counterbalanced; however, the scrolling condition was always presented before the RSVP condition. This was because, the scrolling text display speed and the RSVP text display was matched as close as possible, to control for speed as a confounding factor. Before each text display was presented, all participants completed a short practice trial. During the practice trial for the scrolling text display, the speed (measured in wpm) was calculated and during the test passage, this was then inputted as wpm for the RSVP condition. Participants read each passage aloud and were recorded using a digital recorder to analyse reading errors. After completing each passage, participants were then given the primary YARC comprehension questions which were read out verbally and took on average 15 minutes per text display. The Bailey-Lovie Visual Acuity chart (distance visual acuity, see Table 2) was used to measure distance visual acuity binocularly. Participants were instructed to read the letters row by row until they could no longer able to read letters further down the chart.

Results

Data from all participants (n=37) were included in the final analyses. The analyses were conducted using the statistical package for the social sciences (SPSS, IBM). For the analyses within-subjects one-way ANOVA's (with multiple comparisons correction) were conducted alongside pairwise comparisons to assess reading comprehension (literal, inference and overall) wish each text display type (scroll, RSVP, single-line static text and multiline paragraph format) and reading speed (calculated in wpm). Finally, reading accuracy was also assessed. All of these scores were converted into percentages. The final analyses included reading speed (wpm), the comprehension scores (total, inference and literal scores) and reading accuracy scores (reading errors).

Figure 28

Reading speed in words per minute for all four text display types (scrolling text, RSVP, single-line static text and multiline paragraph format.

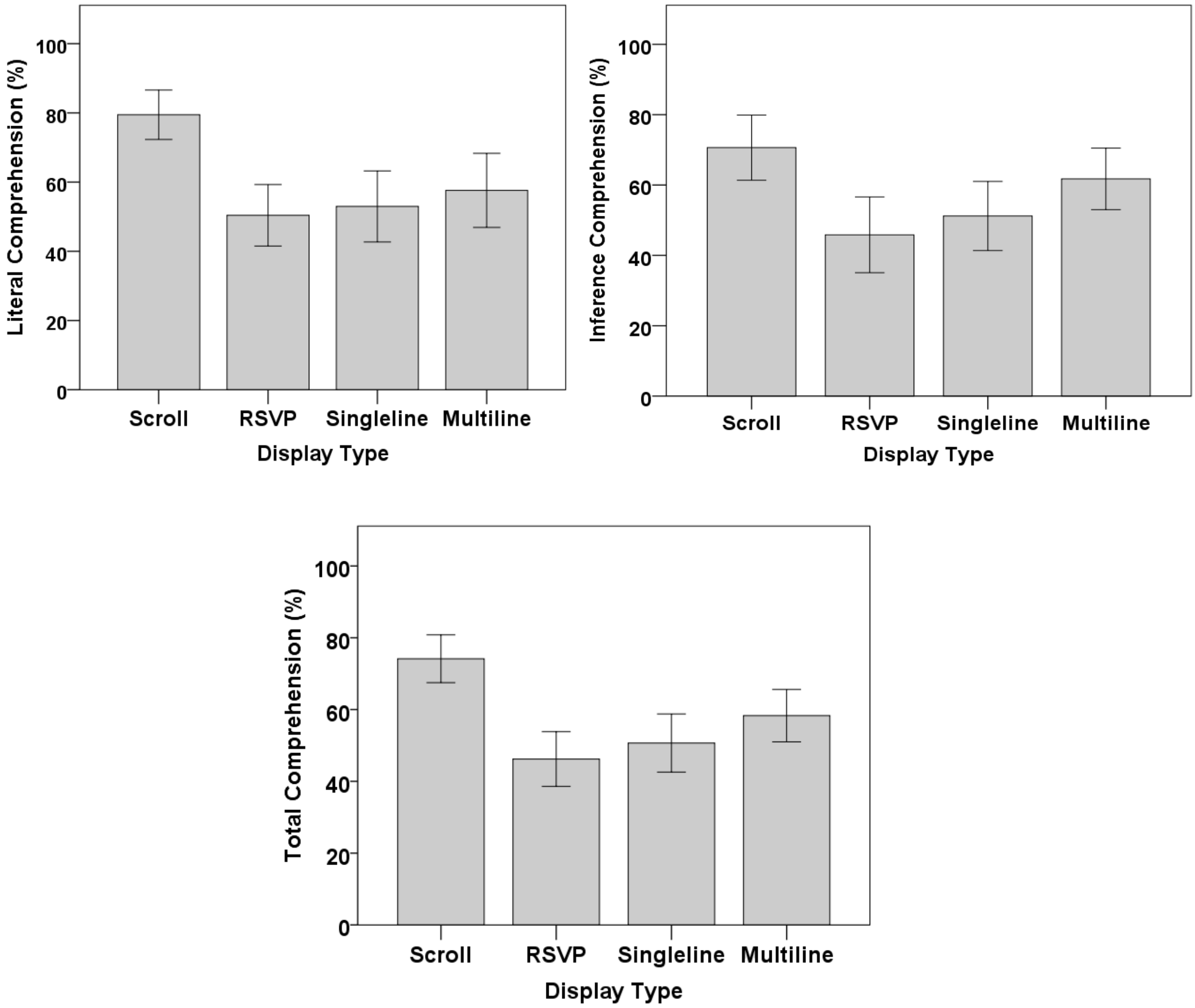


Average reading speed (wpm) is shown in Figure 28 and appears comparable for the two dynamic text displays at around 70 wpm, with a faster rate of some 100 wpm for both static text formats. For the scrolling text display (M = 71.90, SE = 3.84) and RSVP text display (M = 71.70, SE = 3.79) a speed (wpm) was selected by each participant separately during the practice trial at which they felt comfortable reading at. The scrolling text display was given first before the RSVP text display for all participants during the practice and main session and speed was matched as close as possible to one another. The scrolling text format was given first because RSVP can typically be read at faster reading rates that would be unsuitable for scrolling text, this was established during a separate pilot study. The speed was averaged across all participants and only a small difference is observed in the actual reading rate, so this technique appears to have been successful. The fastest reading rate was observed with the two static text formats that were also similar (multiline - M = 104.72 wpm, SE = 6.80; single-line - M = 102.11 wpm, SE = 7.78). A within-subjects one-way ANOVA indicated an overall effect of reading speed on display type, F (3, 108) = 19.96, $p < 0.001$, $\eta^2_G = 0.17$. Further analyses of pairwise comparisons indicated that the single-line static text was read faster than the scrolling text display, $t(36) = 4.46$, $p < 0.001$ and the RSVP text display, $t(36) = 4.44$, $p < 0.001$. The multiline text display was also read faster than the scrolling text display, $t(36) = 4.90$, $p < 0.001$ and the RSVP text display, $t(36) = 4.91$, $p < 0.001$.

Reading Comprehension

Figure 29

Average comprehension scores of literal comprehension (top left), inferential comprehension (top right) and overall comprehension (lower) for the scrolling, RSVP, single-line and multiline text displays.



Reading with scrolling text resulted in the highest literal based comprehension scores (M = 79.46%, SE = 3.58) see Figure 29, top left) compared to the RSVP text display (M = 50.41%, SE = 4.45, single-line static text display (M = 52.97%, SE = 5.13) and the multiline paragraph format (M = 59.23%, SE = 5.59). A within-subjects one-way ANOVA confirmed an statistically significant effect of display type on the literal based comprehension scores, $F(3,108) = 7.71$, $p < 0.001$, $\eta^2_G = 0.75$. Pairwise comparisons indicated better literal comprehension scores with the scrolling text format than the RSVP format, $t(36) = 5.20$, single-line static text $t(36) = 3.91$, $p < 0.001$ and the single-line static text display, $t(36) = 3.91$, $p < 0.001$. The pairwise comparisons also showed that reading with the scrolling text display resulted better literal comprehension than the multiline static paragraph format $t(36) = 2.76$, $p < 0.01$. All other pairwise comparisons were statistically non-significant ($p > 0.05$).

Figure 29 (top right) displays the inferential based comprehension scores. Reading with the scrolling text display resulted in better inferential scores (M = 70.64%, SE = 4.64) than the RSVP text display (M = 45.85%, SE = 5.39) and the single-line static text display (M = 51.21%, SE = 4.91). The one-way ANOVA confirmed an overall effect of display type on the inferential comprehension scores, $F(3,108) = 5.78$, $p = 0.001$, $\eta^2_G = 0.62$. Pairwise comparisons indicated that the scrolling text display resulted in better inference based scores than the RSVP text display, $t(36) = 3.55$, $p < 0.01$ and single-line static text display, $t(36) = 2.96$, $p < 0.01$. However, pairwise comparisons between the scrolling text display and the multiline static paragraph format (M = 58.59, SE = 4.77) were statistically non-significant ($p = 0.07$).

The overall (total) reading comprehension (see Figure 29, bottom, comprised of literal and inference scores), shows a robust improvement with the scrolling text display

(*M* = 74.15%, *SE* = 3.33) than with RSVP (*M* = 46.22%, *SE* = 3.81), the single-line static text display (*M* = 50.66%, *SE* = 4.05) and multiline paragraph format (*M* = 58.31%, *SE* = 3.65). A one-way ANOVA also confirmed an effect of display type on the overall comprehension scores $F(3,108) = 13.02$, $p < 0.001$, $\eta^2_G = 0.77$. Further analyses of pairwise comparisons showed that the scrolling text display produced significant higher comprehension than the RSVP text display, $t(36) = 5.83$, $p < 0.001$, single-line static text display, $t(36) = 4.61$, $p < 0.001$ and the multiline paragraph format, $t(36) = 3.15$, $p < 0.01$.

Figure 30

Percentage of reading errors made whilst reading with the scrolling, RSVP, single-line static and multiline paragraph text displays.

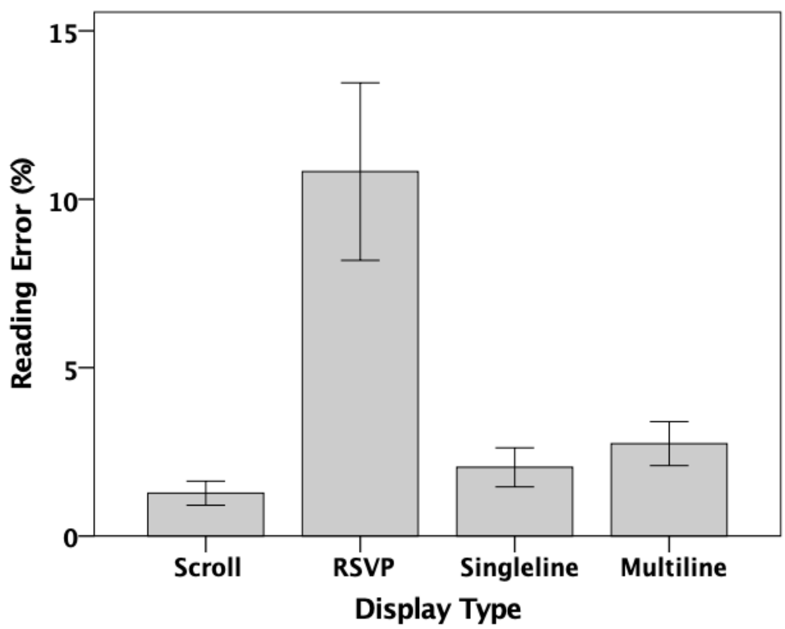
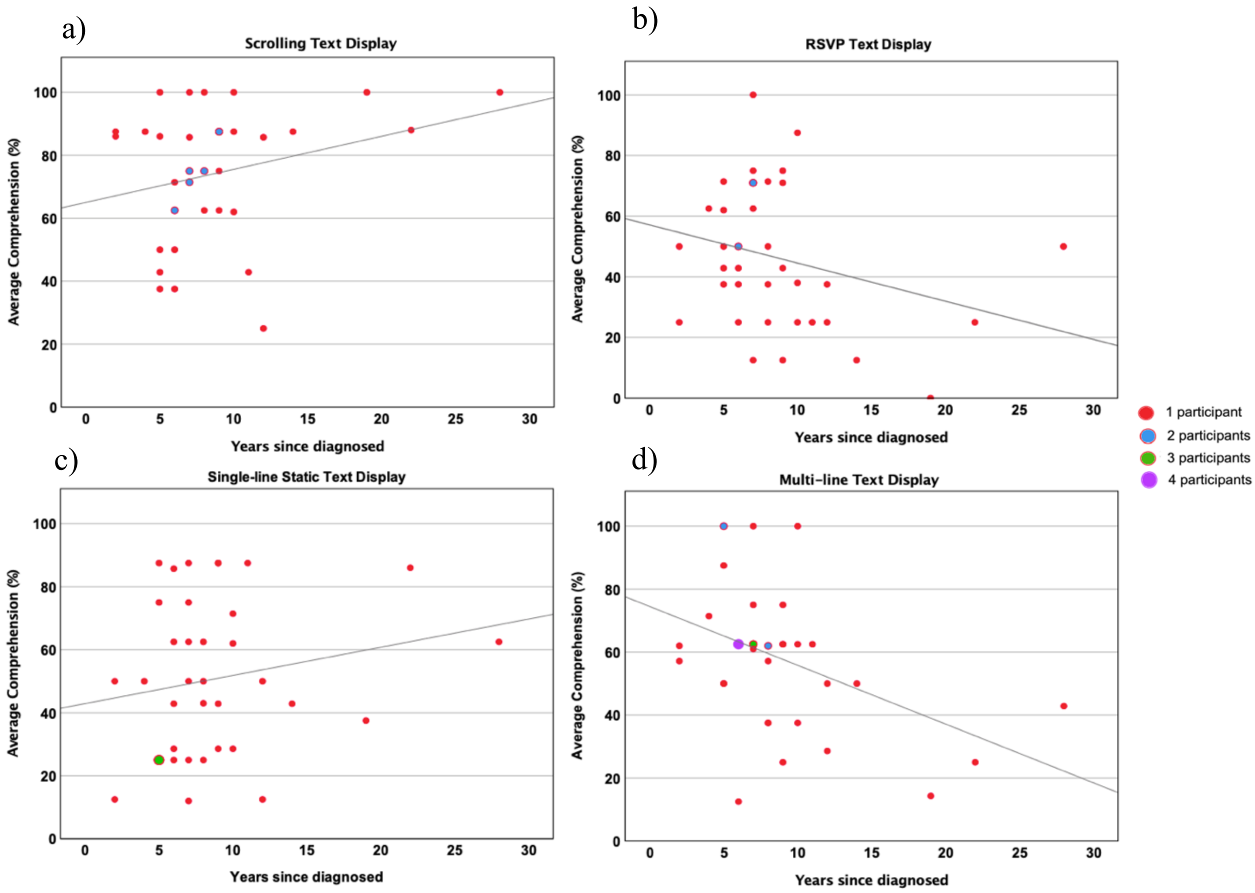


Figure 30 shows the average number of reading errors made with each text format. Reading errors consisted of words which were substituted, inserted and omissions during reading. There was an overall significant effect of reading accuracy on display type, $F(3,108) = 12.94$, $p = 0.001$, $\eta^2_G = 0.17$. Reading with the RSVP text display (M = 11.39%, SE = 2.76) resulted in significantly higher errors than the scrolling text display (M = 1.35%, SE = 0.38), single-line static text display (M = 2.13%, SE = 0.69) and multiline paragraph format (M = 2.82%, SE = 0.69). Further pairwise comparisons indicated that the RSVP text display resulted in significantly more reading errors than the scrolling text display $t(34) = 3.96$, $p < 0.001$, single line static text display, $t(34) = 3.52$ and multiline paragraph format, $t(34) = 3.46$; both at $p < 0.01$. All other comparisons were statistically non-significant ($p > 0.05$).

Comprehension vs Years since Diagnosed

Figure 31

Scatterplots showing the association between the number of years diagnosed and average comprehension score with the a) scrolling text display, b) RSVP text display, c) single-line static text display and d) the multiline paragraph format.

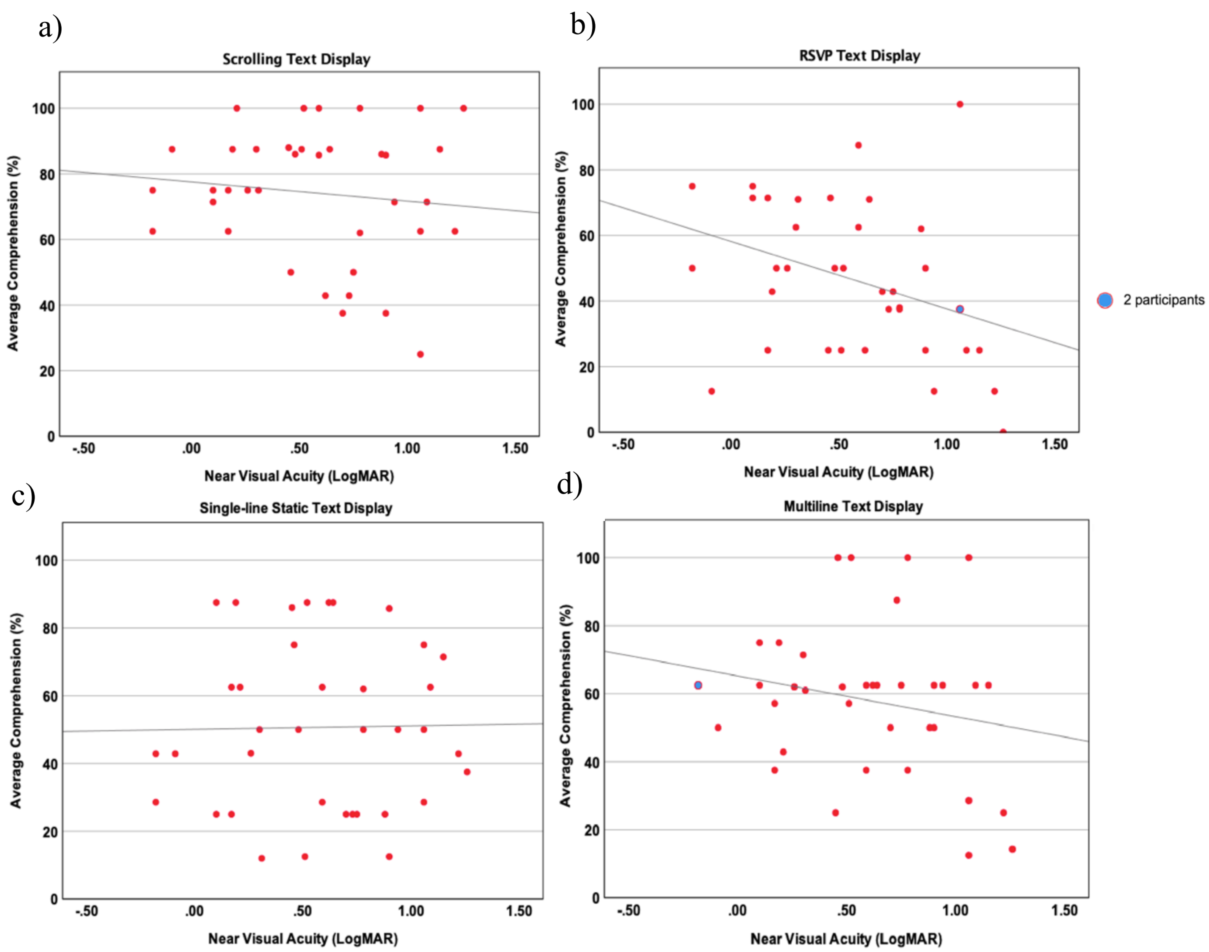


A correlation was performed to examine the relationship between the years since diagnosed and its effect on total (overall, inferential and literal) comprehension. Typically, the trend for the scrolling text display and single-line static text display shows a non-significant trend of a positive correlation where a high comprehension score was still achieved even when the length of diagnosis was longer. However, with the RSVP and multiline paragraph format, a non-significant trend of a negative correlation is apparent where the longer the years since being diagnosed the worse the comprehension score. There were no significant correlations except with the single-line static text display where there was a moderately negative correlation between comprehension score and years since diagnosed with the multiline paragraph format, $r(37) = -0.43$, $p = 0.007$. The trends displayed in Figure 31 suggest that reading with multiline paragraph format results in poor comprehension overall. However, reading with single-line static text can enhance comprehension and scrolling text further aids reading comprehension.

Comprehension vs Visual Acuity

Figure 32

Scatterplots showing the association between the near visual acuity (logMAR) and average comprehension score with the a) scrolling text display, b) RSVP text display, c) Single-line static text display and d) the multiline paragraph format.



A second correlation (Figure 32) examined the relationship between the near visual acuity (measured in logMAR) and its effect on comprehension score. There were no significant differences except with the RSVP text display where there was a moderately positive correlation between comprehension score and near visual acuity, $r(37) = 0.39$, $p = 0.017$.

Discussion

This study aimed to examine reading performance (reading comprehension and accuracy) with dynamic (scrolling and rapid serial visual presentation, *RSVP*) and static text (single-line and multiline paragraph format) presentation, with a loss of central vision. It was hypothesised that firstly, participants will have better reading performance (comprehension and accuracy) with the scrolling text display compared to the RSVP and static text presentations, thus being consistent with findings of Experiment 1b (Chapter 2). In addition to this, this study sought to examine whether findings from the laboratory-based study (Experiment 1b) with an artificial scotoma simulating a loss of central vision could be generalised to people with an actual loss of central vision as a result of macular degeneration.

The findings showed that reading performance (comprehension and accuracy) was better with the scrolling text display (thus supporting the hypothesis) compared to RSVP and static text presentations. Reading performance with the RSVP text display was the poorest compared to scrolling and static text presentations. This was also consistent with the laboratory-based study Experiment 1b with people reading with an artificial scotoma (simulating a loss of central vision), where inferential, gist and overall comprehension as better when reading with the scrolling text presentation. These findings indicated that reading with scrolling text with an artificial scotoma in the laboratory can be generalised to people with an actual loss of central vision. Although literal comprehension was better with the RSVP text display with people reading with an artificial scotoma, it is important to note that for both groups (people with an artificial scotoma and people with macular degeneration), RSVP produced the highest proportion of reading errors compared to scrolling and static text presentations.

The consistently better reading performance observed with both groups of participants (artificial scotoma and actual CVL) may be as a result of numerous factors. Firstly, scrolling text enables the reader to steadily fixate on each separate word for a length of time which is centred around the readers continuing cognitive processing and demands whilst also allowing for the peripheral preview (i.e., parafoveal preview) of upcoming text; necessary for reading fluently (Schotter et al., 2012), which the RSVP text display does not allow. Secondly, reading with scrolling text reduces the demands on the eye movement system especially if scrolling text is used in conjunction with reading strategies such as eccentric viewing and the steady eye strategy by possibly reducing the number of counterproductive fixations which are made directly onto the text whilst reading (Harvey & Walker, 2014) ultimately improving reading quality. Therefore, scrolling text may be particularly beneficial as a reading aid for people with CVL because it enables the reader to make less eye movements to actively find the text, potentially reducing the possibility of counterproductive oculomotor movement (Harvey & Walker, 2014). In addition, scrolling text (presented as a single-line of text scrolling horizontally from right to left) may overcome the challenges faced when reading with static text such as interline crowding (Blackmore-Wright et al., 2013) and navigation including adopting numerous preferred retinal loci to inspect various parts of a block of text as well as eliminating the need to make complex multi-step sequence to move the eyes to the start of a new line (Deruaz et al., 2002; Harvey & Walker, 2014).

The poor reading performance observed with the RSVP text display may be as a result of a variety of factors. Firstly, RSVP removes the need to make any eye movements during reading (Masson, 1983; Rayner, 2009). Previous research has suggested that the elimination of all eye movements may not be as advantageous as instead it may enhance cognitive overload and divert attention away from the content of the text being read (Bouma & De Voogd, 1974). Moreover, in this case standard RSVP was adopted (words were presented in sequential order one after the other at a constant speed). Previous research has further suggested that the control over the sequence and the duration of word processing as well as the control over eye movements are essential for a high level of comprehension, consequently the inability to make regressions to go back over text to re-inspect it has a negative effect on comprehension (Schotter et al., 2014). Furthermore, the inability to make regressions may consequently result in the reader having to make an informed guess showing a lower level of understanding, leading to the reader to prioritise single-word processing with a decreased level of integration between words. This further may be exacerbated by the decline of cognitive resources (for example, working memory) that are accessible to preserve items in the working memory due to the greater attentional load (Kennedy, 1982; Kerzel & Ziegler, 2005).

Another important factor which may have detrimental effects on reading with RSVP is the removal of the parafoveal preview that is possible with static text and also scrolling text. The parafoveal preview allows information to be obtained about words which are not directly fixated upon yet (Rayner, 2009). This allows the reader to process the word with much more ease when the word is fixated upon as a result of previously obtaining information before actually fixating on the word (Schotter et al., 2012). It is also important to note that visual fatigue may also be a factor which affects reading with RSVP. Visual fatigue is also referred to as asthenopia and eye strain which is defined by tiredness and pain around the eyes with blurry vision and/or a headache (Benedetto et al., 2015). Reading with RSVP results in a reduction of eye blinks which are minimised if tasks involve continuous visual attention and will instead occur before or after the task (Stern et al., 1984). Previous research has suggested that eyeblinks are implicated with the attentional disengagement whilst carrying out a cognitive task by briefly initiating the default mode network and disengaging the dorsal attention network. As reading with the RSVP text display requires an increased level of visual attention, a decreased number of eye blinks is inevitable (Benedetto et al., 2015; Nakano et al., 2013). On the other hand, reading with scrolling text maintains both the parafoveal preview and the ability to go back over words to re-inspect them (regressions), which may have contributed to more fluent reading and increased comprehension or understanding of the passage. Thus, RSVP may be a poor method for reading with normal vision and also for people with a loss of central vision.

Another interesting observation is the correlations between average comprehension and number of years diagnosed and near visual acuity. There was one significant moderately negative correlation between number of years diagnosed and comprehension score with the multiline paragraph format. This indicates that reading with multiline paragraph format becomes increasingly difficult as the number of years diagnosed increases. This may be as a result of known issues reading with multiline text with CVL such as navigation and fixation stability (Bellmann et al., 2004). This further emphasises the need to use other reading formats such as scrolling text which may overcome these challenges resulting in more effective reading with CVL (Walker et al., 2016).

One of the major investigations of this study was to see if results could be generalised from the laboratory-based study with an artificial scotoma (simulating a loss of central vision) to actual people with CVL. Although a major caveat of this study is the lack of eye movement data with people who are diagnosed with macular degeneration, the laboratory-based study eye movements (with an artificial central scotoma) showed that participants adopted an eye movement strategy which was counterproductive and did not adhere to the eccentric viewing strategy. Instead, participants attempted to mimic the normal pattern of eye movements when reading with some attempts of trying to adopt the eccentric viewing strategy. Thus, it is suggestive that participants were unable to overcome the strong natural tendency of eye movement behaviour as a result of adopting an oculomotor strategy which was ineffective. The trends of the correlation of people with macular degeneration suggest that people with macular degeneration may be better at adhering to the eccentric viewing strategy as a result of not having a choice as a genuine loss of central vision is experienced. The longer the individual is diagnosed, the correlations show (although non-significant) with scrolling and single-line static text displays indicate a higher comprehension score suggesting participants are using a strategy which has helped them to read the text and comprehend the text with these text displays. Nevertheless, the comprehension results (i.e., both showing consistently better reading performance with scrolling text) from both studies with people with an artificial scotoma and people with macular degeneration are comparable. This indicated that, to an extent, findings from the laboratory-based study with an artificial scotoma can be generalised to people with an actual loss of central vision.

The present study extends previous literature (Bernard et al., 2007; Fine & Peli, 1995b; Legge, Ross, Maxwell, et al., 1989; Rubin & Turano, 1992; Scherlen et al., 2008) which primarily focused on reading speed with a loss of central vision, by including detailed measures of reading comprehension (the ultimate goal of reading) and reading accuracy. In addition, the results of this study support those of Harvey & Walker (2014) who reported that reading with a scrolling text display improved reading accuracy compared to static text displays. This may be due to the ease of adopting an eccentric viewing position during the scrolling text display and fewer eye movements needed to read the text, compared to the static texts. Therefore, supporting the idea that the use of an eccentric viewing position as an effective method for central field loss rehabilitation for those with low vision and CVL (Jeong & Moon, 2011). Additionally, the enhanced comprehension and higher accuracy with the scrolling text display may be as a result of its ability to display more information on a limited sized screen compared to the other text displays (Kang & Mutar, 1989). This allows for consistency and a better flow of reading allowing for better reading comprehension. More importantly, scrolling text enables normal processes such as the parafoveal preview and fixation duration that reflect on-going cognitive demands further potentially allowing for the better use of an adaptive strategy. Although it is speculative that people with macular degeneration are using a different oculomotor strategy to those displayed with people with an artificial scotoma, there is a possibility that people with macular degeneration are better able to use a strategy or potentially hold their gaze eccentrically when text scrolls further aiding their ability to see the text better rather than searching left and right.

A possible consideration in relation to this study is the selection of font size used. The CPS assessed using the digital MNREAD near distance visual acuity chart (iPad version) calculated for each participant which was then doubled as the font size used in the main study. This further allowed for the same standardised procedure to be adopted across all of the participants, which enabled a consistent and rigid procedure. However, this may have simultaneously affected reading comprehension with the RSVP text display as previous literature has proposed RSVP to be beneficial for reading speed when font is 8 times the acuity threshold (Fine & Peli, 1998). Although this may be the case, in this particular experiment, reading speed was not the focus nor measure of the study thus, to control for reading rate as a factor of comprehension it was necessary to match the font size across all four text display types. It is also important to note the difference in the near and distant visual acuity for some of the participants. Although all of the participants did self-report having CVL in at least one eye, being diagnosed with macular degeneration and no other eye pathologies, the differences in visual acuity may mean that some participants may have had other eye conditions (e.g., cataracts) without the participant being aware. In addition to this, it may be the case that the difference in visual acuity may be as a result of having an eye which is not as affected by macular degeneration thus driving the better binocular acuity. Therefore, another caveat with this study was the inability of checking the back of the eyes of participants and gaining clinical data to establish whether participants had a central scotoma and confirming no other pathologies were present. Nevertheless, this study provides further evidence of the benefits of using scrolling text presentation for people with a loss of central vision as a potential reading aid.

Chapter 4.

The effectiveness of including biofeedback (auditory warning signal) to improve adherence to eccentric viewing behaviour

Introduction

The most common clinical reported problem and primary goal for individuals pursuing visual rehabilitation is reading. Reading is a complex process which depends largely on numerous psychophysical and cognitive systems (Markowitz et al., 2018). Typically, low vision rehabilitation can be distinguished into two categories. The first category implements low vision aids such as magnification equipment, telescopes and devices. The second category aims to target the training of visual function to optimise the patient's remaining residual vision which can be used to facilitate daily tasks such as reading (Jeong & Moon, 2011). This is done through two strategies; eccentric viewing (Timberlake et al., 1987; Whittaker et al., 1988) and steady eye strategy (Watson & Berg, 1983).

The eccentric viewing strategy involves implementing a non-foveal location on the retina for visual tasks. In a healthy retina, the fovea; located in the centre of the macula, is used for fixation however, when there is damage to the central retina, the eye compensates by adopting a new retinal location used for viewing. This new retinal location is known as the preferred retinal locus (PRL) which typically takes the place of the fovea, vital for eccentric viewing training. In most cases the adoption of a PRL occurs naturally after central vision loss however in other cases, typically older patients, need to be trained and educated as a consequence of the scotoma and how to function visually around this (Jeong & Moon, 2011). These strategies help train the patient to control their eye movements and place the object of interest on a particular location of the retina by finding a peripheral area of the retina where the tissue is healthy and where the individual can see and focus the best. Adopting these reading strategies requires time, dedication and concentration as the individual must overcome the typical reflex of the oculomotor system (Gaffney et al., 2014).

Modern technology can further facilitate reading for people with central vision loss by displaying text on tablets or using eReaders, that enable users to change various characteristics of the text such as text colour, text size, background colour, contrast, brightness (etc), which are all features useful for those with visual impairments. The way in which text is presented can also be altered for instance, displaying text dynamically rather than the conventional static text. Forms of dynamic text presentations include horizontally scrolling text (also called drifting text and Times Square format as it resembles a news ticker) and RSVP. Scrolling text involves a single line of text that scrolls horizontally, from right-to-left, across the screen. The use of scrolling text has numerous applications for instance, the ability to display unlimited text in defined spaces when reading normally and the adoption of scrolling text as a way to implement reading strategies (such as eccentric viewing and steady eye strategy) for individuals with impaired vision. This is achieved by minimising the number of eye movements necessary to read such text resulting in improved reading comprehension, accuracy and speed (Bowers et al., 2004; Harvey & Walker, 2014; Legge et al., 1985; Legge, Ross, Maxwell, et al., 1989; Lin & Shieh, 2006; Walker et al., 2016). RSVP may be beneficial for those with visual impairments as eye movements are not necessary to read the text, making it easier to implement the steady-eye strategy (Rubin & Turano, 1992, 1994). Previous findings from this thesis (Chapter 2 and Chapter 3) and research (Harvey & Walker, 2014;

Legge, Ross, Luebker, et al., 1989; Legge, Ross, Maxwell, et al., 1989; Legge, Rubin, et al., 1985; Robin Walker et al., 2016) have found that horizontally scrolling text results in an improved reading comprehension and reading accuracy which is sustained compared to RSVP, which is more beneficial for reading speed (Kang & Muter, 1989; Rubin & Turano, 1992, 1994). However, a possible caveat with RSVP may be poor understanding or comprehension and increasing visual fatigue (Benedetto et al., 2015). Nevertheless, with readers who are normally sighted, scrolling text is reported to have a higher subjective-user preference than the RSVP text display (Bowers et al., 2004; Lin & Shieh, 2006).

There are a variety of different interventions, some of which may be used together for people with macular degeneration and a loss of central vision. As there are no effective medical cures for macular degeneration, but only treatments which delay the disease progression, these interventions are essential to help people with macular degeneration to continue with their daily activities such as reading (Pijnacker et al., 2011). Some of the interventions include, the eccentric viewing technique, oculomotor control, fixation stability, PRL relocation and perceptual learning (Tarita-Nistor et al., 2014). There is no particular recommendation or preference of one specific training technique or strategy for rehabilitation for this clinical group. However, there is evidence that people with macular degeneration are able to use perceptual learning as a way of enhancing reading performance within a short time frame (Pijnacker et al., 2011). Perceptual learning or also referred to as training or practice, is classified as *"any relatively permanent and consistent change in the perception of a stimulus array, after practice or experience with this array"* (Chung, 2011, p. 1164).

Numerous studies have reported that visual performance is enhanced with perceptual learning for a variety of visual tasks such as the identification or differentiation of particular stimulus patterns (Astle et al., 2015; Chung, 2011; Greenlee et al., 2014; Pijnacker et al., 2011). Chung (2011) examined the usefulness of utilising perceptual learning to aid reading rate with individuals (n=6) with CVL. All participants practiced with six weekly sessions reading 300 sentences with the RSVP format. Chung (2011) found that the RSVP reading rate improved as a result of perceptual learning. Chung (2011) proposed that the participants did not alter the location of the functional PRL and fixation stability which suggests that the improvement observed in reading rate is not due to utilising a more functional retinal region with better visual capability or enhancement in fixation. Instead, this improvement is attributed to the perceptual learning itself and it was concluded that perceptual learning may be an effective tool for aiding and improving visual performance for people who have a loss of central vision. In contradiction to Chung (2011), Seiple, Grant, & Szlyk (2011) compared different rehabilitation techniques specifically, the eccentric viewing technique and visual awareness, oculomotor training and practice with RSVP. The oculomotor training included firstly saccadic training (participants made a saccade between dots that were presented) and feedback was given by the experimenter. Secondly, the next training involved letters instead of dots and participants were to comment on the change of letter rather than identification of the letter and this repeated with letter pairs. Participants did not practice adopting eye movements by reading sentences to avoid confounding the outcome measure. It was found that the only strategy that resulted in improvements in reading rate was oculomotor training. However, there were no or very minimal improvements in reading performance when practicing with RSVP (Seiple et al., 2011), in contrast with the findings of Chung (2011).

In order to improve reading the underlying visual skills necessary for reading, such as fixation stability and saccades must be retrained to enhance reading performance (Markowitz et al., 2018). The use of an auditory oculomotor feedback signal can be adopted as a training technique for individuals with macular degeneration which aids the maintenance of reading strategies such as eccentric viewing and steady eye strategy (Markowitz et al., 2018). Auditory biofeedback consists of training attention and eye movements towards a desired location, usually the PRL, where the individual can see and focus the best. The audio biofeedback (controlled by an eye tracker) responds if the individual deviates from the fixation location. The use of the auditory biofeedback stimuli allows the trainer to have control and critical observation ensuring the trainee is maintaining oculomotor control (Markowitz et al., 2018). Additionally, the purpose of the auditory biofeedback signal is to accentuate and intensify attention of one's eye movements with the goal of developing conscious control of the eyes which gradually becomes progressively reflexive (Hall & Ciuffreda, 2001). Previous implementation of this technique with individuals who have a decline of central vision have illustrated that auditory feedback may be useful for maintaining and controlling eye fixation (Smith, 1964) and consistently maintaining vergence (Shelhamer et al., 1994).

The use of an auditory biofeedback strategy in a clinical environment has been implemented to decrease detrimental visual effects of eye movement irregularities such as nystagmus and atypical saccadic movements. For instance, in a study conducted by Verdina et al., (2013) it was found that the use of an auditory biofeedback rehabilitation for patients diagnosed with Stargardt's disease resulted in an enhanced residual visual function due to a normalisation of eccentric fixation (Verdina et al., 2013). Moreover, Vingolo, Salvatore and Cavarretta (2009) demonstrated, although lacking constancy, an improvement of reading speed and visual efficiency as a result of an improvement in PRL fixation stability and retinal sensitivity. It was argued that this improvement using a biofeedback strategy may be a result of training a retinal motor PRL. It was further suggested that the biofeedback strategy may be a result of the brains capability to observe a systematic PRL during visual tasks. The use of an audio biofeedback may facilitate the brain to determine the final PRL by heightening the attentional modulation (Vingolo et al., 2009).

Currently, no studies have explicitly examined improvements in reading performance (comprehension and accuracy) following perceptual learning (in this case defined as, training to be beneficial for reading with central vision loss) (Chung 2011; Yu et al., 2010)) with an auditory biofeedback signal to entrain the use of eccentric viewing when reading static and dynamic (horizontally scrolling and RSVP) text. Although Chung (2011) investigated perceptual learning with the RSVP format, the measure of reading performance used was reading rate. Measuring reading speed, as mentioned previously, is a good psychophysical measure, but is not optimal for comparing reading with static and dynamic text formats. Here comprehension; the ultimate goal of reading (Rubin, 2013) was used as the main measure of interest along with error rates and adherence to eccentric viewing. The use of perceptual learning in conjunction with an auditory biofeedback as a training tool for eccentric reading and to enhance reading performance with CVL may potentially be a useful training tool for people with a loss of central vision.

This chapter describes a laboratory-based study that utilises an artificial-scotoma paradigm with an eye-tracker to simulate a loss of central vision with an auditory biofeedback signal to improve the training of reading with an eccentric viewing position. There are two main aims of this study first, to explore the effectiveness and presence of an auditory biofeedback to train and implement the eccentric viewing strategy and enhance reading performance (comprehension and accuracy). Secondly, to assess whether perceptual learning (in this case defined as, training to be beneficial for reading with central vision loss) (Chung 2011; Yu et al., 2010) is beneficial for improving adherence to eccentric viewing and for enhancing reading performance. Another consideration was the method of text presentation and dynamic (scrolling text and RSVP) and static text formats which were compared. The eye tracker was used to record eye position enabling adherence to eccentric viewing to be assessed. Participants read passages of text in three separate sessions in which they read passages of text in each of the three formats (scrolling, static, RSVP).

The hypotheses of this experiment were firstly, the presence of a biofeedback signal would be beneficial for adhering to the eccentric viewing strategy and enhancing reading performance for all text display types. Secondly, it was hypothesised that perceptual learning would improve reading performance across all three text formats (scroll, RSVP and single line static text). Finally, scrolling text will produce better reading performance overall as observed with previous findings within this thesis.

Method

Participants

Participants were 28 students recruited from Royal Holloway, University of London (*M* = 20.04 years, *SD* = 1.43). All participants had self-reported normal or corrected-to-normal vision (best corrected binocular visual acuity of 0.0logMAR or better), no reading, cognitive or language deficits, and spoke British English as their first language. All of the participants gave informed consent prior to taking part in the study. The study was self-certified in line with the guidelines set by the College Ethics Committee at Royal Holloway, University of London.

Stimulus and Apparatus

The stimulus, apparatus and design, and the gaze-contingent scotoma, were as described for Experiment 1b in Chapter 2. However, in the present study practice passages were stories taken from BBC News (taking approximately 10 minutes to complete per text display) and an additional two passages taken from the secondary YARC battery (see Table 4) were also used for the actual assessment (see Table 1, Chapter 2, Experiment 1b). Each YARC passage ranged from 415 to 476 words in total. Each session took approximately one hour to complete; this included reading practice passages with each format, the standardised passage with each format and completing the comprehension questions after reading. As with Experiment 1b, reading speed was measured through a custom Python code. For the scroll and single line presentations the text was triggered by the gaze contingent square which enabled the timer to start until the participant pressed the space bar (timer stopped) and the gaze contingent square would appear to progress to the next part of the text. For the RSVP text display, once the gaze contingent square was triggered the timer started until the passage was finished being presented where the timer stopped. Steady gaze contingent fixation on this square was required to initiate the start of the trial (requiring a minimum of 40ms to trigger the text allowing for steady fixation). This procedure ensured participants were holding their gaze at the required eccentric viewing location when the sentence(s), or first word in the case of RSVP, appeared on the screen. All participants read aloud, and comprehension was evaluated in the first and last session.

Table 4

Passages (taken from the York Assessment for Reading Comprehension, Secondary Battery) used for reading including the available scores for the literal section, inferential section, summary scores, overall total maximum score and total number of sentences for each passage (Stothard et al., 2009).

Passage of Text	Literal	Inference	Summary	Total maximum score	Total number of sentences
River Girl	3	7	9	10	30
Castaway	7	3	8	10	24

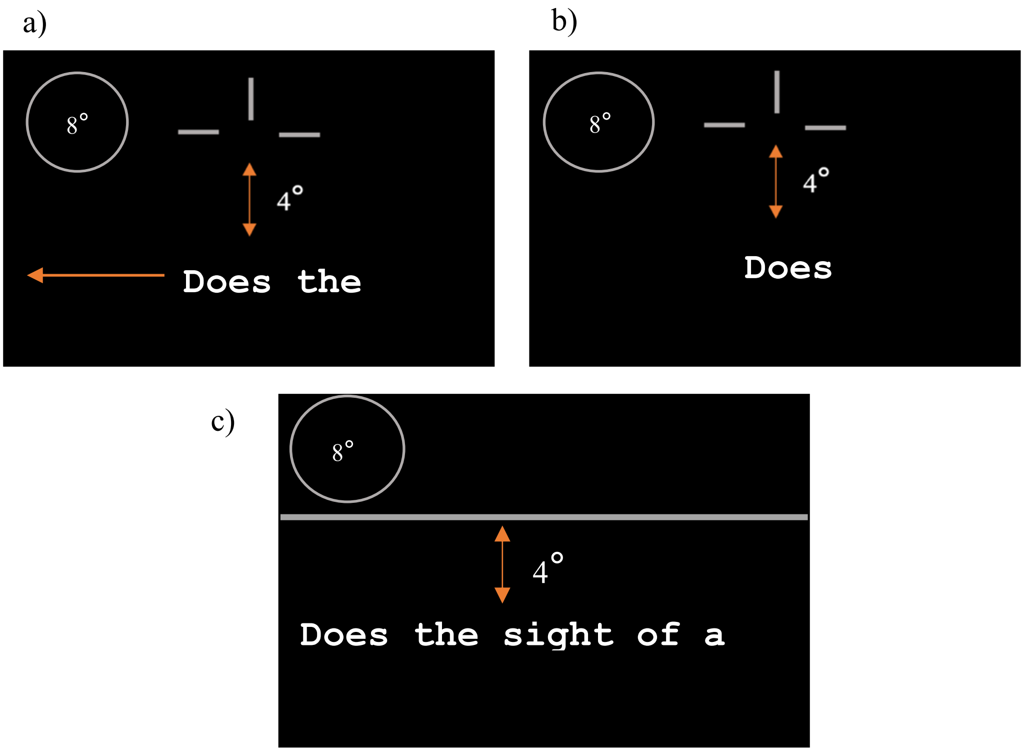
Procedure

All participants completed three sessions, where they read short passages of text (out loud) presented as a single line of horizontally scrolling text, RSVP text and single-line static text format. All participants were informed about eccentric viewing (i.e., what eccentric viewing is and how to implement this with each of the text displays during the practice trial) and asked to adhere to the eccentric viewing position and steady eye strategy for all three text display types (scroll, RSVP, single line static) as best as possible.

All sessions were approximately 3 days apart. A grey guideline was placed above the line of text (4° above the text) for each of the text displays as an aid to adopt reading using eccentric viewing. When participants focused on the guideline, they had a peripheral view of the text (i.e., the text was only covered by the scotoma if the participant looked directly at the text, see Figure 33). The biofeedback auditory signal would be triggered if participants looked in the text ROI. For the horizontally scrolling text and single line static text the text ROI covered the full radius of the text presentation (1920 pixels, width and 211 pixels, height) and for RSVP the text ROI covered the longest word presented (15 characters, 420 pixels wide and 211 pixels high). As soon as the scotoma moved out of the text ROI and into the eccentric viewing region; (for scroll and single line, 1920 pixels width and 384 pixels high and for RSVP, 420 pixels (width) and 384 pixels (height)) located 4° above the text ROI, the biofeedback auditory warning would turn off (for schematic diagram of measurements see Figure 17, Chapter 2).

Figure 33

Schematic diagram of text presentation and guidelines for the a) scrolling text display with scotoma (8°), *b) RSVP text display with scotoma and c) single-line static text display with scotoma. For all text displays the biofeedback was triggered if the scotoma moved into the eccentric viewing ROI (for scroll and single line; 1920 pixels, width and 384 pixels, height and for RSVP; 420 pixels, width and 384 pixels, height).*



This was a 3x2 experimental design where participants were divided into two groups (biofeedback, no biofeedback) and read text presented under the three text displays. Group one (14 participants, M = 20.50, SD = 1.65) received an auditory biofeedback warning signal when they did not maintain the eccentric viewing position (i.e., if the participants viewing position was not in the eccentric viewing ROI), this was done to guide the participants back to adhering to the eccentric viewing position. The auditory warning signal was triggered if participants were not fixated in the eccentric viewing ROI (covering the length of text across the display screen, located 4° above the text ROI, see Figure 17, Chapter 2), the auditory biofeedback played as a continuous pitched sound which would continue to play until the participant moved gaze back to the eccentric viewing region**.**

For both groups, the presentation of the dynamic text displays were matched as far as possible. Scrolling text was presented at 153 wpm (at 100 Hz text moved at 4 pixels every 10ms) and the presentation of each word for the RSVP format was matched as closely as possible to this speed (each word displayed for 389ms) for all participants. This speed was selected based on a prior pilot where the majority of participants selected this speed (4 pixels) as the preferred reading rate out of a selection of 1-6 pixels (38.27 – 191.33 wpm) scrolling speed. This procedure was adopted as it is more appropriate to select a slow speed for the scrolling text and match this to the RSVP as this format enables very high reading speeds that are not possible with scrolling text.

An eye tracker monitored gaze at the eccentric viewing in each ROI and the auditory signal would be triggered if participants deviated to the text ROI (4° below the eccentric viewing ROI), see Figure 17, Chapter 2 for all measurements of the eccentric viewing and text ROIs. Group two (14 participants, $M = 19.57$, $SD = 1.02$) did not receive an auditory biofeedback signal if they deviated away from the eccentric viewing position. For session 1 (baseline session) and session 3 (final session) participants read a practice passage of text before the YARC standardised passage of text. Each practice session consisted of approximately 500-600 words and took on average 20-25 minutes to complete in total (across all text displays). Thus, all together, including the YARC passage, participants read a total of 30 minutes for session one and three. Once reading the standardised YARC passage, participants were given comprehension questions. For session two (practice session) participants read one passage of text taken from BBC news consisting of around 700-800 words and (roughly took around 45 minutes in total for all text display types combined). There were no questions given after this passage of text was read as this was a practice session. All passages were counterbalanced across participants. Therefore, in total there were three sessions each lasting one hour each for both the biofeedback and no biofeedback groups. Reading errors were also recorded as well as eye movements.

Analyses

All analyses were carried out using R studio (2020) to analyse the data. ANOVA's and Wilcoxon paired ranked tests were computed to analyse reading speed, performance (comprehension and accuracy) and adherence to the eccentric viewing strategy for each of the text displays, groups and sessions. For all post-hoc tests, multiple comparisons corrections were applied.

Results

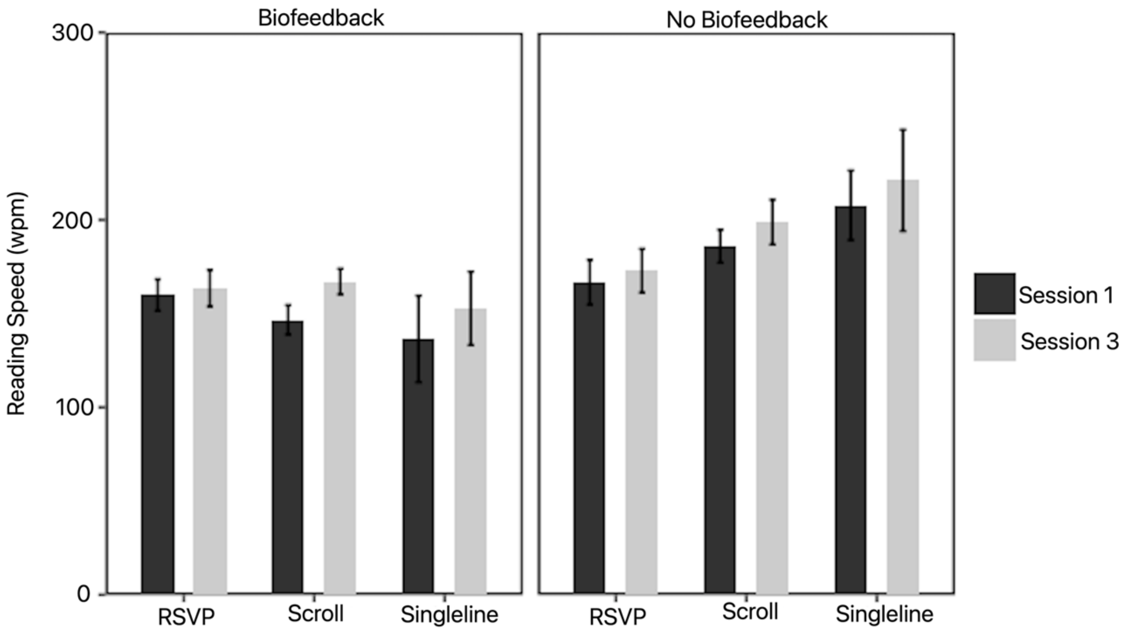
Reading speed

The reading speed was calculated as the time spend reading in wpm with each passage in session one and three for all text display types. To examine reading speed, a 2x2x3 mixed ANOVA was computed (group, session and display). For all reading performance analyses (speed, comprehension and accuracy) and eye movement analyses a Shapiro-wilk test was conducted to check distribution of the data which indicated that measures were not normally distributed. Therefore, Wilcoxon signed-rank tests were used, as this does not assume normality within the data and replaces dependent t-tests which assume normality. The Wilcoxon signed rank tests were used to compare speed, comprehension scores and for the eye movement analyses from session one to three for each group with the scroll, RSVP and single-line static text displays.

Figure 34 displays the reading speed (wpm) for both the biofeedback and no biofeedback groups for each text display type (RSVP, scroll and single line). It can be observed in Figure 34 that that for the RSVP text display for both groups, speed is fairly similar. However, with the scrolling text presentation and single line static presentation there is an increase in reading rate with the no biofeedback group from session one to session three. Although the presentation speed was fixed, it is important to note that the speed of dynamic text presentation was matched as close as possible by the program being used, therefore although speed was matched there can be some variations in speed however this should not be a big difference between the two dynamic text presentations.

Figure 34

Reading speed in words per minute (wpm) with the RSVP, scroll and single-line static text presentation across session one and session three with the biofeedback (left) and no biofeedback (right) groups.



The mixed ANOVA indicated an overall significant main effect of biofeedback, F (1,26) = 9.83, $p < 0.01$, $\eta^2G = 0.11$, indicating reading speed was faster without a biofeedback compared to with a biofeedback signal. There were no other significant main effects or interactions (see Table 5).

Table 5

2-way interaction effects of display, perceptual learning, group and display, group and perceptual learning, display and perceptual learning and three-way interaction effect of group, display and perceptual learning, F and P values for reading speed.

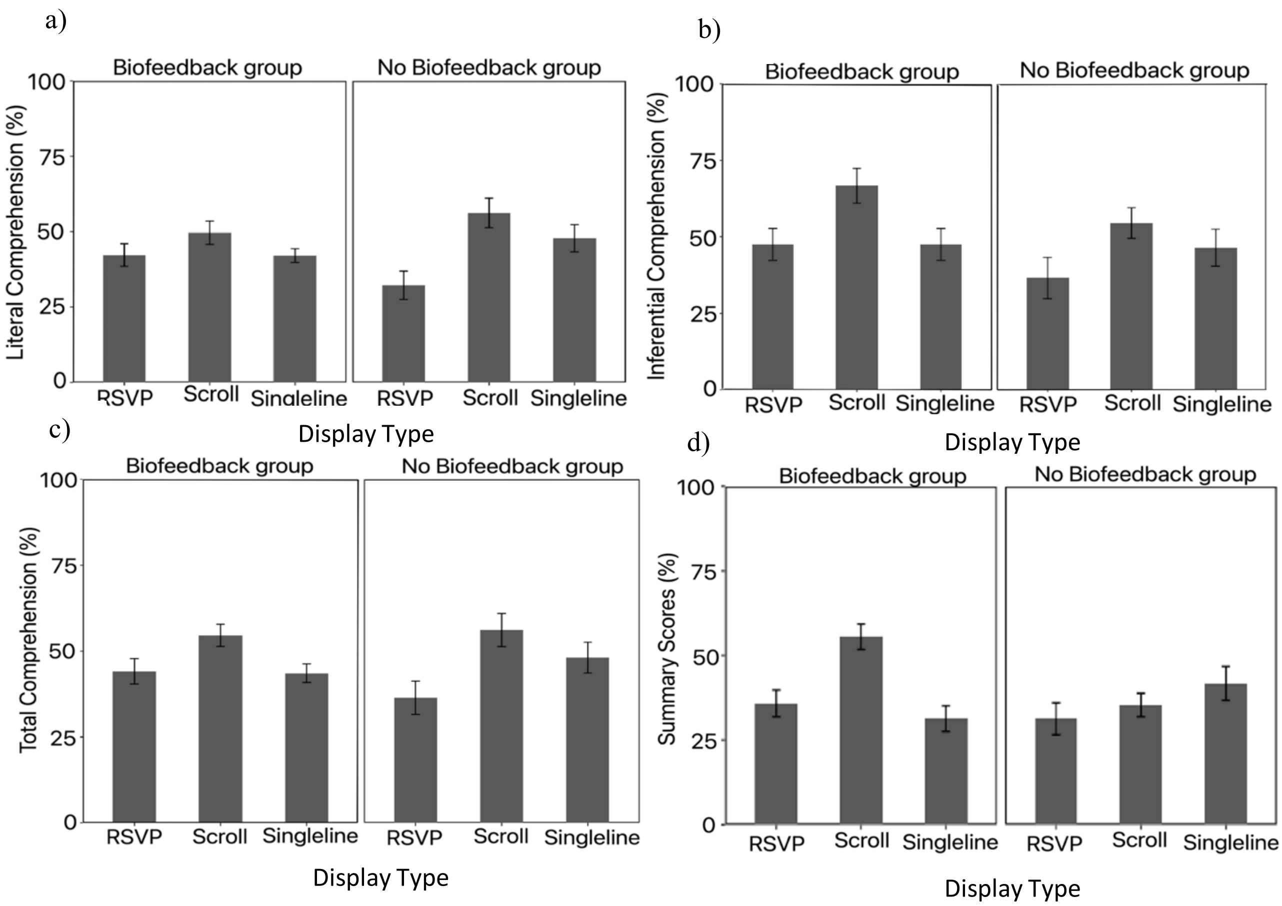
Effect	Statistic
Display	$F\ (2,52) = 0.61, p = 0.54, \eta^2G = 0.01$
Perceptual Learning	$F\ (1,26) = 3.49, p = 0.07, \eta^2G = 0.01$
Group x Display	$F\ (2,52) = 3.02, p = 0.06, \eta^2G = 0.05$
Group x Perceptual Learning	$F\ (1,26) = 0.04, p = 0.84, \eta^2G < 0.01$
Display x Perceptual Learning	$F\ (2,52) = 0.42, p = 0.66, \eta^2G < 0.01$
Group x Display x Perceptual Learning	$F\ (2,52) = 0.06, p = 0.94, \eta^2G < 0.01$

Reading Comprehension

To analyse reading comprehension, separate 2x2x3 mixed ANOVAs (group, perceptual learning and display) examined the effect of group (2), perceptual learning (2) and text format (3) on each of the main measures of interest (literal, inferential, and total comprehension and summary gist). Figure 35 displays the biofeedback results for the literal (a), inferential (b), and total comprehension scores (c) and summary scores (d) in percentages for all three text display types (RSVP, scroll and single line) for the biofeedback and no biofeedback groups. Figure 36 displays the perceptual learning results for literal (a), inferential (b), and total comprehension (c) and summary scores (d) in percentages for all three text display types (RSVP, scroll and single line) for the biofeedback and no biofeedback groups for session one and session three.

Figure 35

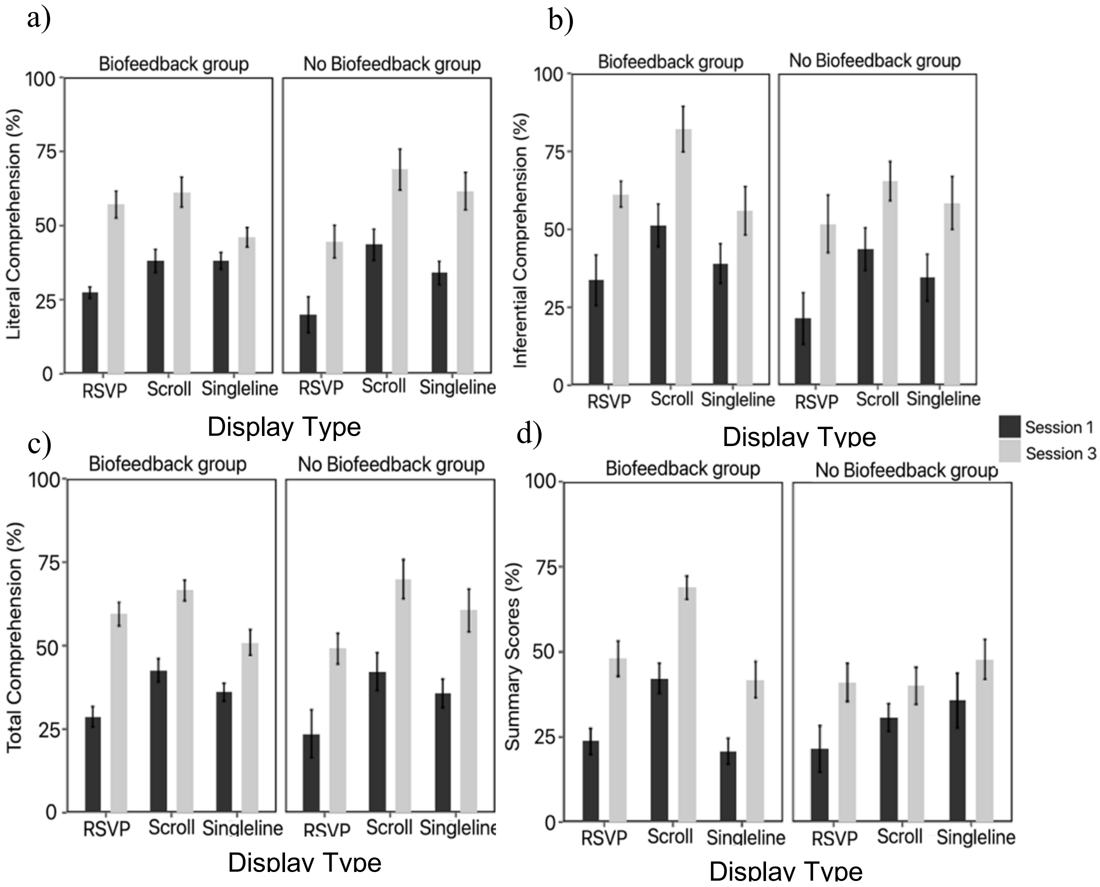
Average percentage comprehension for the biofeedback and no biofeedback groups for each text display type, a) literal comprehension, b) inferential comprehension, c) total comprehension scores and d) summary comprehension scores.



From Figure 35 there appears to be no influence of biofeedback but performance appears better with scrolling text and worst with RSVP. For each measure of comprehension (except summary scores for no biofeedback group Fig 35d), it is observable that the scrolling text format produced consistently higher comprehension scores for the literal, inferential total and summary scores. By contrast the RSVP text can be observed to produce consistently lower comprehension scores for both the biofeedback and no biofeedback groups.

Figure 36

Average percentage comprehension for the biofeedback and no biofeedback groups for each text display type, a) literal comprehension, b) inferential comprehension, c) total comprehension scores and d) summary comprehension scores for session one and session three.



From Figure 36 it can be observed that comprehension increases from session one to session three for all three text displays and across groups. For both groups (biofeedback and no biofeedback) there is an improvement of comprehension scores for all measures (literal, inferential, total and summary scores) from session one to session three. For both groups and all comprehension measures scrolling text appears to produce better comprehension scores after training, with the exception of the summary scores for the no biofeedback group where there seems to be a smaller difference of scores from session one to three across all text display types.

The mixed ANOVA showed no significant effect of biofeedback for literal comprehension (F(1,26) = 0.04, p = 0.83, η^2G = 0.01), inferential comprehension (F(1,26) = 3.62, p = 0.07, η^2G = 0.02), total comprehension (F(1,26) = 0.02, p = 0.88, η^2G < 0.01) and summary scores (F(1,26) = 1.81, p = 0.19, η^2G = 0.02). Perceptual learning was, effective for enhancing literal (F(1,26) = 77.21, p < 0.001), inferential (F(1,26) = 42.86, p < 0.001, η^2G = 0.18), total (F(1,26) = 104.91, p < 0.001) and summary comprehension scores (F(1,26) = 38.65, p < 0.001, η^2G = 0.19) that all showed a significant increase in comprehension from session one to session three. There was also a significant main effect of text display: for literal comprehension (F(2,52) = 12.74, p < 0.001, η^2G = 0.12), inferential comprehension (F(2,52) = 6.03, p = 0.004, η^2G = 0.08), total comprehension (F(2,52) = 10.79, p < 0.001, η^2G = 0.12) and summary scores (F(2,52) = 7.03, p = 0.002, η^2G = 0.07). Wilcoxon paired-rank tests (see Table 6) showed that the scrolling text display resulted in better comprehension (literal, inferential total and summary) compared to both RSVP and single line static text displays. Literal comprehension scores were significantly higher with the single line static text compared to the RSVP text. There were no other significant differences for the other comprehension measures (inferential, total and summary) between the RSVP and single line static text presentations (see Table 6).

The majority of two-way interactions (except 2 of the interactions) and the three-way interactions (biofeedback and perceptual learning, biofeedback and display type, display type and perceptual learning and biofeedback display type and perceptual learning) were statistically non-significant for the literal, inferential, total and summary scores (see Table 7).

Table 6

Wilcoxon Paired Rank test p-values for the literal, inferential, total and summary comprehension measured for each text display type.

Comprehension measure	Scroll and RSVP	Scroll and Single line	RSVP and Single line
Literal	< 0.001	0.03	0.04
Inferential	0.005	0.02	0.69
Total	< 0.001	0.02	0.22
Summary	0.004	0.05	0.99

Table 7

2-way interaction effects of group and perceptual learning, group and display type, display type and perceptual learning and three-way interaction effect of group, display type and perceptual learning, F and P values for the literal, inferential, total and summary scores.

Comprehension measure	Group and perceptual learning	Group and display type	Display type and perceptual learning	Group, Display type and perceptual learning
Literal	$F(1,26) = 1.13$, $p = 0.30$, $\eta^2G = 0.01$	$F(2,52) = 4.50$, $p = 0.02$, $\eta^2G = 0.05$)	$F(2,52) = 1.11$, $p = 0.34$, $\eta^2G = 0.01$	$F(2,52) = 1.92$, $p = 0.16$, $\eta^2G = 0.02$
Inferential	$F(1,26) = 0.96$, $p = 0.98$, $\eta^2G < 0.01$	($F(2,52) = 0.61$, $p = 0.55$, $\eta^2G < 0.01$)	$F(2,52) = 0.37$, $p = 0.69$, $\eta^2G < 0.01$	$F(2,52) = 0.33$, $p = 0.72$, $\eta^2G < 0.01$

Total	$F(1,26) = 0.34$, $p = 0.57$, $\eta^2G < 0.01$	($F(2,52) = 1.90$, $p = 0.16$, $\eta^2G = 0.01$).	$F(2,52) = 1.00$, $p = 0.37$, $\eta^2G = 0.01$	$F(2,52) = 0.82$, $p = 0.45$, $\eta^2G = 0.01$
Summary	$F(1,26) = 2.90$, $p = 0.10$, $\eta^2G = 0.02$	($F(2,52) = 10.73$, $p < 0.001$, $\eta^2G = 0.01$).	$F(2,52) = 0.26$, $p = 0.77$, $\eta^2G = < 0.01$	$F(2,52) = 0.34$, $p = 0.71$, $\eta^2G < 0.01$

From Table 7 it can be seen that the only significant 2-way interactions were between group and display type for literal comprehension and the summary scores. For literal comprehension, Wilcoxon paired rank tests indicated that with the no biofeedback group, the scrolling text display produced significantly higher literal comprehension scores than the RSVP text display ($p < 0.001$) and the single line static text display produced higher literal comprehension scores than the RSVP text display ($p = 0.03$). There was no significant difference between the scrolling and single line static text displays ($p = 0.07$), or with the biofeedback group (all $p \geq 0.09$). For the summary (gist) comprehension scores, Wilcoxon paired rank tests indicated that for the biofeedback group, the scrolling text display resulted in better summary scores than the RSVP text display ($p = 0.003$) and the single line static text display ($p < 0.001$). There were no significant differences between the RSVP and single line static text displays ($p = 0.99$). There were also no significant differences with the no biofeedback group (all $p > 0.60$) of interactions of biofeedback and text display presentations for the inferential ($F(2,52) = 0.61$, $p = 0.55$, $\eta^2G < 0.01$) and total comprehension ($F(2,52) = 1.90$, $p = 0.16$).

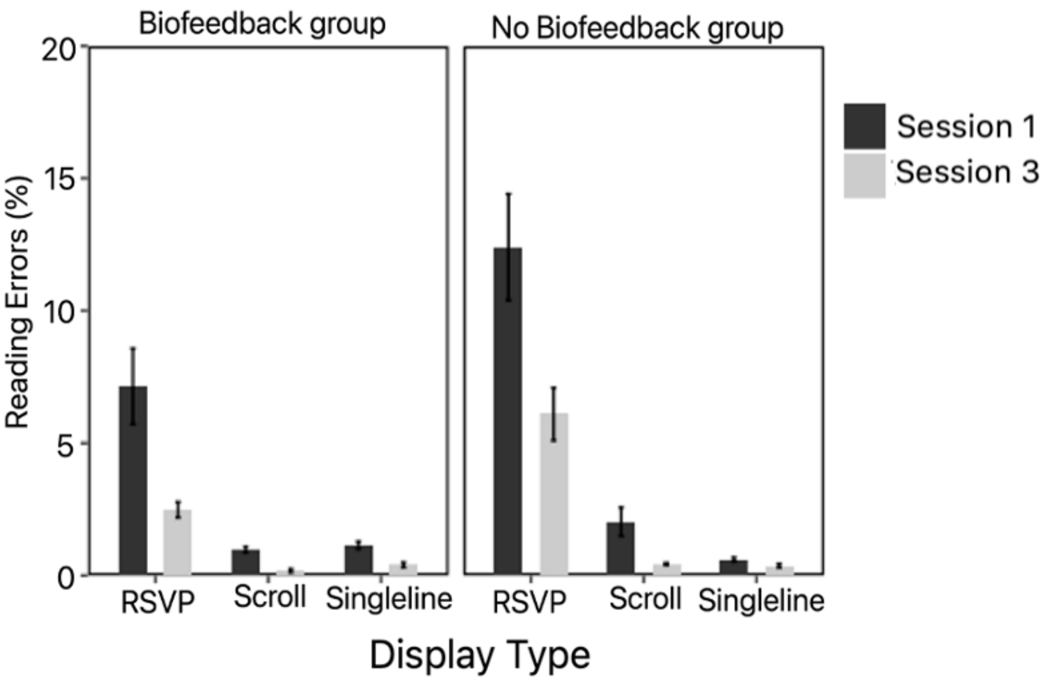
In summary, there is some evidence for the effectiveness of biofeedback, as shown by the interaction effect of group x display with the summary (gist) comprehension with the biofeedback group which indicated better gist comprehension with the scrolling text display compared to the RSVP and static text presentations. In addition, there was a strong effect of perceptual learning for all comprehension types (literal, inferential, total and summary) across all three display displays, this can be observed from Figure 36. Thus overall, the effect of biofeedback may be more useful for gist comprehension; the overall meaning and context of a written passage and taking away the main points of text (measured through summary scores) and this is enhanced with the scrolling text display. All three text displays benefitted from perceptual learning for enhancing comprehension, with the scrolling text producing better comprehension scores (literal, inferential, total and summary) compared to other text display presentations.

Reading Error rates

Reading errors (defined as missed, substituted or incorrect words whilst reading) are displayed in Figure 37 and are low for all text formats except RSVP. It can be seen that for both groups (biofeedback group and no biofeedback) there is a decrease in reading errors from session one to session three for all three text display types. More reading errors can be observed with the no biofeedback group compared to the biofeedback group.

Figure 37

Percentage of reading errors observed for each text display type (RSVP, scroll and single-line) across session one and three for the biofeedback group (left) and no biofeedback group (right).



Error rates were examined in a 2x2x3 mixed ANOVA (group, session and display) which confirmed that a biofeedback was effective for improving reading accuracy ($F(1,26) = 10.46$, $p = 0.003$, $\eta^2G = 0.07$), compared to the no biofeedback which produced significantly more reading errors. Perceptual learning was also effective in reducing reading errors from session one to session three ($F(1,26) = 41.49$, $p < 0.001$, $\eta^2G = 0.15$). There was a significant main effect of text display type on reading errors ($F(1,26) = 10.46$, $p = 0.003$, $\eta^2G = 0.52$). Wilcoxon paired rank tests indicated that there were significantly more reading errors made with the RSVP text display compared to the scrolling text display ($p < 0.001$) and the single line static text display ($p < 0.001$). There were no significant differences of reading errors between the scrolling and single line static text display types ($p = 0.99$).

There was a significant two-way interaction effect of group and text display type ($F(2,52) = 7.47$, $p = 0.001$, $\eta^2G = 0.11$). Wilcoxon paired rank tests indicated that for the biofeedback group, the RSVP text display resulted in significantly more reading errors than the scrolling text display ($p < 0.001$) and single line static text display ($p < 0.001$), however there were no significant differences between the scroll and single line static text displays ($p = 0.23$). For the no biofeedback group, the RSVP text display again produced significantly more reading errors than the scrolling text display ($p < 0.001$) and single line static text displays ($p < 0.001$). The scrolling text display resulted in significantly less errors compared to the single line static text display ($p = 0.03$). There was a significant two-way interaction between text display and perceptual learning ($F(2,52) = 15.51$, $p < 0.001$, $\eta^2G = 0.13$), explained by a difference in the magnitude of decrease in reading errors from session one to session three (all $p < 0.001$; greater improvement with the RSVP text display ($M = 7.03$, $SE = 0.76$) compared to the scrolling ($M = 0.91$, $SE = 0.14$) and single line static text display ($M = 0.63$, $SE = 0.05$). This is accounted for by the high error rate in session one with RSVP. The interactions of biofeedback and perceptual learning ($F(1,26) = 0.77$, $p = 0.39$, $\eta^2G < 0.01$) and the three way interaction effect of biofeedback, text display type and perceptual learning ($F(2,52) = 0.63$, $p = 0.54$, $\eta^2G = 0.01$) were non-significant.

In summary, the presence of biofeedback was partially effective - resulting in fewer errors than those participants with no biofeedback, demonstrating that biofeedback may be more useful for reading accuracy than for comprehension. In addition, the interaction suggests that this is driven by the RSVP format as a result of the poor performance in session one thus there was more room for improvement with this format. The scroll and static text formats produced very low error rates and therefore there was less room for improvement with practice (i.e., floor effect). Perceptual learning was effective, with improvement in reading accuracy from first to last session, again demonstrating that all text formats benefitted from practice. Reading with single-line and scrolling text resulted in better reading accuracy compared to the RSVP format.

Eye Movement Analyses

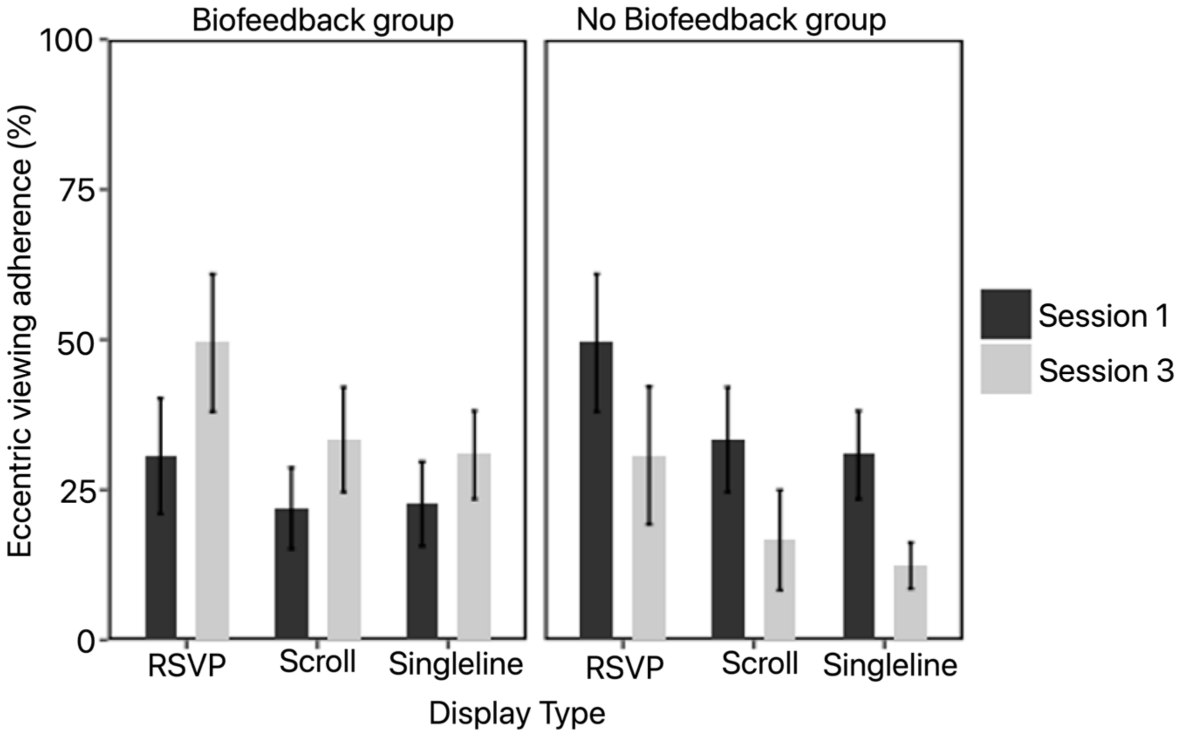
Adherence to eccentric viewing was examined as the proportion of time spent eccentrically fixating (time spent, in percentage, fixating within the eccentric ROI) for all three text displays for sessions one and three for each group was examined. The individual fixation positions for each participant were also examined for all three text displays and sessions for each group.

Adherence to eccentric viewing

Figure 37 shows the percentage of time spent eccentrically viewing (measured through the time spent eccentrically fixating within the eccentric ROI, located 4° above text and the text ROI located 4° below the eccentric viewing region (see Figure 17, Chapter 2 for measurements of the eccentric viewing and text ROIs). Again, as with Experiment 1b, the location of fixations was classified in line with these ROIs drawn (i.e., fixations made in the eccentric region and fixations made in the text region).

Figure 38

Percentage of time spent eccentrically viewing for each text display type for each group in session one and session three.



From Figure 38 it can be observed that the biofeedback group shows better adherence to the eccentric viewing strategy across all three text display types, with perceptual learning. By contrast, the no biofeedback group show decreased adherence to the eccentric viewing strategy after perceptual learning across all text formats. Thus, the presence of a biofeedback appears to enhance eccentric viewing.

A mixed ANOVA 2x2x3 (session, group and display) was computed to assess the proportion of time spent fixating eccentrically for each group and session across all three text display types. There was no overall significant main effect of biofeedback $F(1,26) = 0.11$, $p = 0.75$, $\eta^2G < 0.01$ or perceptual learning ($F(1,26) = 0.12$, $p = 0.73$, $\eta^2G < 0.01$). However, there was a main effect of text display type ($F(2,52) = 11.12$, $p < 0.001$, $\eta^2G =$

0.05), where the adherence to eccentric viewing was better maintained with the RSVP text display compared to the scrolling text display (p = 0.005) and single-line static text display (p = 0.01). There were no significant differences in eccentric viewing adherence between the scrolling and single line static text presentations (p = 0.99). There was however, a 2-way interaction of biofeedback and perceptual learning ($F(1,26) = 4.36$, $p < 0.05$, $\eta^2G = 0.06$), where a biofeedback signal resulted in better adherence to eccentric viewing in session three (p = 0.02) and the no biofeedback group were worse at adhering to eccentric viewing in session three (p = 0.03). All other 2-way interactions such as biofeedback and display type ($F(1,26) = 0.12$, $p = 0.73$, $\eta^2G < 0.01$), display type and perceptual learning ($F(2,52) = 0.21$, $p = 0.81$, $\eta^2G < 0.01$) and three-way interactions including biofeedback, display type and perceptual learning ($F(2,52) = 0.28$, $p = 0.76$, $\eta^2G < 0.01$) were statistically non-significant.

Figure 39

Individual fixation positions for all participants for the biofeedback group for both session one and session three. The first line (red) represents the eccentric viewing region of interest and the second line (blue) displays the text region of interest. From left to right- scrolling text, RSVP, static text, upper shows session 1 and lower plots session 3.

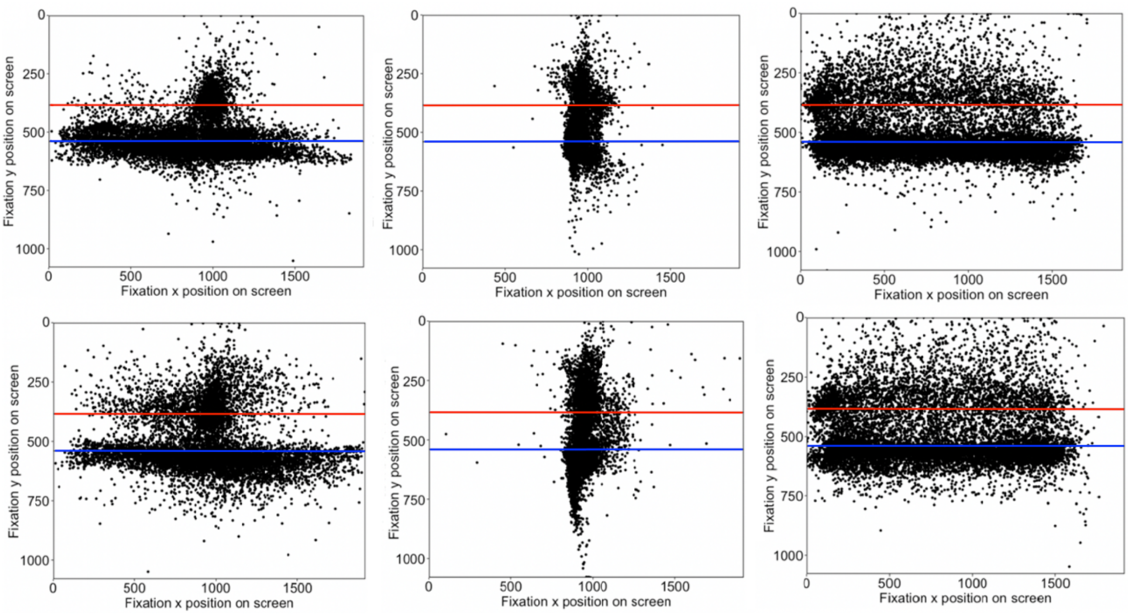


Figure 40

Individual fixation positions for all participants for the non-biofeedback group for both session one and session three. The first line (red) represents the eccentric viewing region of interest and the second line (blue) displays the text region of interest. From left to right- scrolling text, RSVP, static text, upper shows session 1 and lower plots session 3.

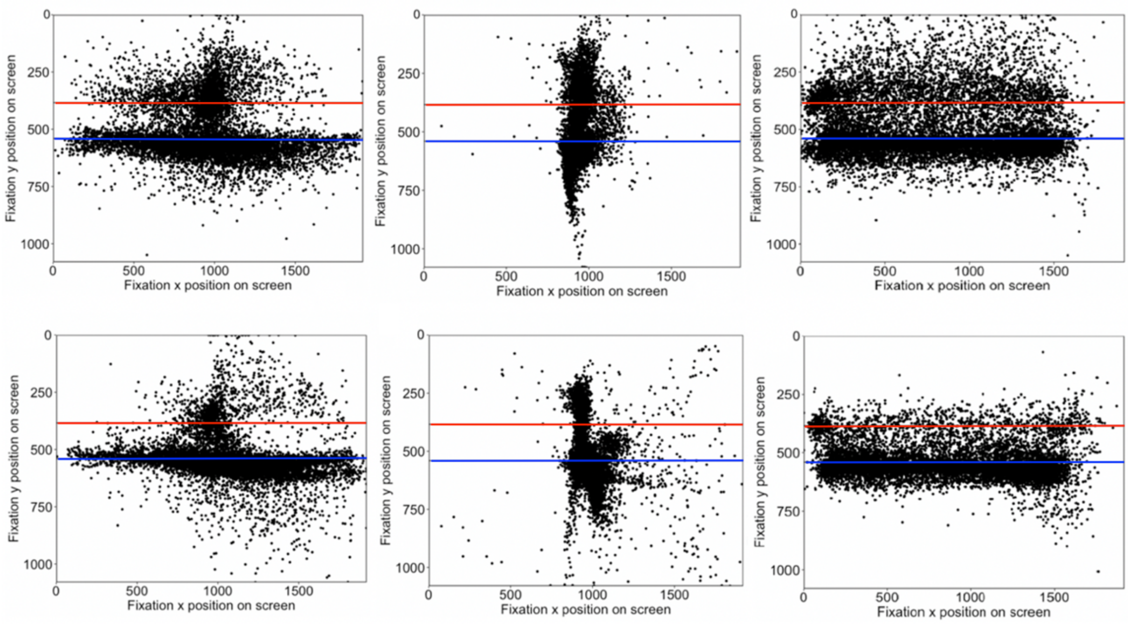
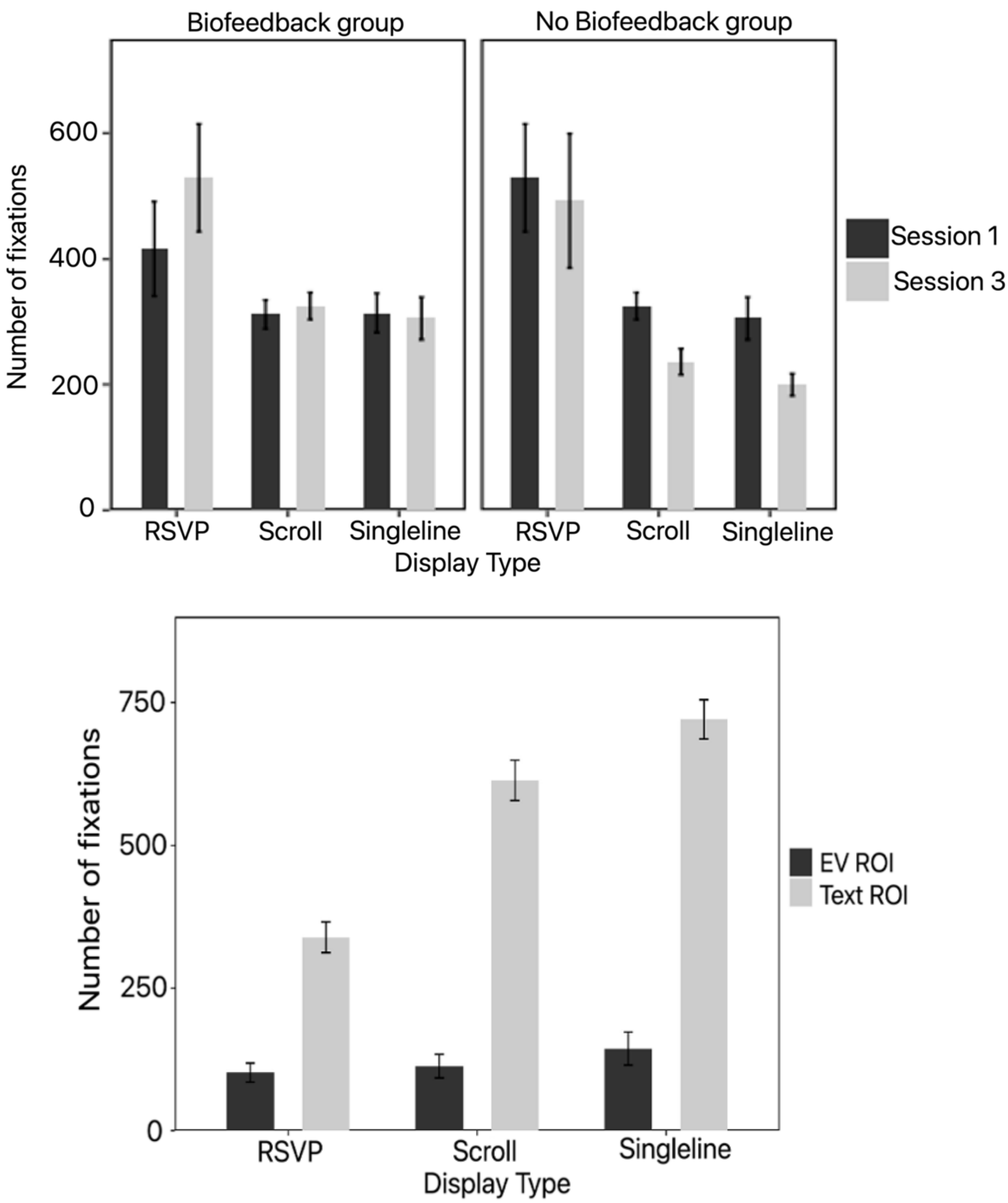


Figure 41

Upper plot shows the total number of fixations made by the biofeedback and no biofeedback group for each text display type (RSVP, scroll and single-line static text displays) in session one and session three and lower plot shows the total number of fixations made in the RSVP, scroll and single line static text displays in each region of interest (text and eccentric viewing, EV).



In order to analyse the fixations made in each ROI (eccentric viewing location and on the text) for each group (biofeedback and no biofeedback) across sessions (perceptual learning) for each text display type (scroll, RSVP and single line) a 2x2x2x3 (group, session, ROI and display) mixed ANOVA was computed for fixation count.

From Figure 41, it appears there is little difference in the number of fixations made for each text display type across the sessions. The plots indicate an increase in fixation positions on the text ROI compared to the eccentric viewing ROI and there are more fixations on the text in session one than session three. This is also consistent with the impression from the individual fixation positions (see Figures 39 and 40). A mixed ANOVA confirmed this observation, there was no significant effect of group on fixation positions ($F(1,26) = 2.01$, $p = 0.17$, $\eta^2G = 0.01$). Thus, the presence of a biofeedback had no effect on fixation positions. However, there was a significant effect of perceptual learning ($F(2,52) = 43.26$, $p < 0.001$, $\eta^2G = 0.01$) from session one to session three. Participants made significantly more fixations on the text ROI compared to the eccentric viewing ROI ($F(1,26) = 85.40$, $p < 0.00$, $\eta^2G = 0.55$). Wilcoxon paired rank tests indicated that there were significantly fewer fixations made on the text in session three compared to session one ($p = 0.01$), with no significant differences of fixations positions in the eccentric viewing region from session one to session three ($p = 0.40$).

Finally, there was a significant effect of text display presentation on fixation count ($F(2,52) = 43.26$, $p < 0.001$, $\eta^2G = 0.16$). Wilcoxon paired rank tests indicated that there were significantly more fixations made on the text region with the scrolling and single line static text displays compared to the RSVP text displays (both $p < 0.001$). In addition, there were significantly more fixations made on the text with the single line static text presentation than the scrolling text presentation ($p < 0.01$).

All interactions except one were non-significant (see Table 8). There was a significant interaction between display and ROI ($F(2,52) = 27.31$, $p < 0.001$, $\eta^2G = 0.17$, $\eta^2G = 0.12$) and session and ROI ($F(2,52) = 4.33$, $p < 0.05$, $\eta^2G = 0.02$). Further Wilcoxon paired rank tests indicated that the scrolling and single line static text displays resulted in more fixations on the text compared to the RSVP text display.

Table 8

Non-significant interactions for fixation positions including the F and P values for each interaction.

Interaction	Statistic
Biofeedback x Display	$F(2,52) = 1.24$, $p = 0.30$, $\eta^2G < 0.01$
Biofeedback x Perceptual learning	$F(1,26) = 0.00$, $p = 0.95$, $\eta^2G < 0.01$
Biofeedback x ROI	$F(1,26) = 1.35$, $p = 0.26$, $\eta^2G = 0.02$
Display x Session	$F(2,52) = 1.44$, $p = 0.25$, $\eta^2G < 0.01$
Biofeedback x Display x Perceptual learning	$F(2,52) = 0.02$, $p = 0.98$, $\eta^2G < 0.01$
Biofeedback x display x ROI	$F(2,52) = 0.31$, $p =0.73$, $\eta^2G < 0.01$
Biofeedback x Perceptual learning x ROI	$F(1, 26) = 0.66$, $p = 0.42$, $\eta^2G < 0.01$
Display x Perceptual learning x ROI	$F(2,52) = 0.47$, $p =0.63$, $\eta^2G < 0.01$
Biofeedback x Display x Perceptual learning x ROI	$F(2,52) = 0.37$, $p = 0.69$, $\eta^2G < 0.01$

In summary, the eye movement analysis indicated that the presence of biofeedback was effective for improving maintenance to eccentric viewing, and there was better adherence to eccentric viewing in session three with biofeedback compared to without biofeedback. In addition, the adherence to eccentric viewing was better with the RSVP text display compared to the scroll and single line static text display. For fixation positions, biofeedback was ineffective, however, for perceptual learning there were more fixations made on the text in session one compared to session three. Consistent with the adherence to eccentric viewing, the RSVP text display resulted in fewer fixations on the text compared to the scroll and single line static text displays. Although it is noteworthy that the single-line static text display resulted in more fixations on the text compared to the scrolling text display.

Discussion

This study examined the effectiveness of including an auditory biofeedback warning signal to enhance reading performance and to help train to maintain reading using the eccentric viewing strategy with a simulated central scotoma. The results indicated that the presence of an auditory biofeedback signal was only effective for enhancing summary or gist comprehension (the ability to understand main points and messages within a passage of text) and this comprehension measure (measured through summary scores) was enhanced with the scrolling text display compared to the RSVP and static text presentations. Although there were no other significant effects of a biofeedback for all other comprehension measures, there was evidence that it was effective for improving adherence to the eccentric viewing strategy. There was better adherence to eccentric viewing in session three compared to session one. However, despite the improvement of eccentric viewing with biofeedback, especially with the RSVP text display, reading comprehension and reading accuracy was poor with this format. The results indicated that perceptual learning was also useful for improving fixation positions on the text meaning that there were significantly less fixation positions made on the text (participants looked at the text less) in session three compared to session one. It should be noted that the presence of biofeedback was also partially useful for enhancing reading accuracy where there were significantly less errors made from session one to session three in the biofeedback group for all text display types with the biggest improvement with the RSVP text display (as expected as there were significantly more errors made with this format in session one, thus a bigger scope for improvement). This may potentially be a result of the eye movement behaviour, where there was better adherence to eccentric viewing and less fixations on the text resulting in a better view of the text.

The inclusion of a biofeedback signal was not useful for reading performance or adherence to eccentric viewing. The pattern of eye movements observed with scrolling text shows a tendency to look at the text. Legge, Ross, Luebker, et al., (1989) and Buettner et al., (1985) have shown that when reading scrolling text the eyes firstly being fixated on one letter, secondly the letter is tracked across the display with a distance of four to five character spaces and finally a saccade is made to identify a new letter. The findings in this experiment with an artificial scotoma (and Chapter 2 also with an artificial scotoma) demonstrate that people reading with a simulated loss of central vision adopt a similar strategy despite being asked to reading using the eccentric viewing strategy. However, an important key difference between participants with normal vision and those reading with a central scotoma may be that participants reading with a scotoma adopt a left-right scanning behaviour. The eye movement data indicates that participants were not adhering to the eccentric viewing strategy however instead adopt a pattern of left-right scanning on the text with many up-down saccades, which may be as a result of instructing participants to adopt eccentric viewing strategy. It is possible that if participants were not instructed to do this, they would have mostly used the strategy of left to right scanning behaviour on the text (this pattern of eye movement was also observed in Chapter 2). It is also important to note that participants were only instructed to adopt the eccentric viewing strategy, it may also be useful to train participants using the steady eye strategy in future studies. Nevertheless, for reasons which are unclear, participants' perception of text is evidently better with the scrolling text display. A speculation may be that it supports the left to right scanning behaviour, and this may in turn enhance peripheral perception of moving text.

Secondly, this study examined whether perceptual learning was effective in enhancing reading performance and if the biofeedback signal would produce greater effects of practice. The findings showed a strong effect of perceptual learning for enhancing reading performance for all comprehension measures (literal, inferential, total and summary). The scrolling text format resulted in consistently better reading performance compared to the RSVP and static text presentations. In addition, perceptual learning was also beneficial for enhancing eccentric viewing where better adherence was observed in session three. The number of fixations made on the text from session one to session three also reduced indicating that perceptual learning was effective. The effect of perceptual learning in enhancing reading performance and adherence to eccentric viewing indicates the usefulness of training for these measures with a loss of central vision (in this case an artificial central scotoma). This also provides evidence for the usefulness and effectiveness of perceptual learning.

Finally, the study examined if there were any differences (as a result of perceptual learning and an auditory biofeedback signal) across the text formats which were used (horizontally scrolling text, RSVP and single line static text). Overall, the scrolling text display produced consistently better reading comprehension scores compared to the other text displays and the RSVP format consistently resulted in poorer comprehension scores and high error rates. Perceptual learning had a strong effect on comprehension and accuracy where there were was a greater improvement of reading accuracy with the RSVP text display. Although it should be noted that this may be driven by the RSVP format where there were significantly more reading errors made in session one compared to the scroll and single-line static text displays. Therefore, the potential for improvement with the RSVP text display was higher compared to the other formats which had relatively low reading errors. The finding of increased comprehension scores with scrolling text and the poorer reading comprehension observed with RSVP is consistent and supports findings in previous chapters within this thesis (see Chapters 2 and 3). Nevertheless, all text formats (scroll, RSVP and single line static text) gained positively from the chance to train (i.e., perceptual learning), this can be observed in Figures 34 and 35.

Previous research examining perceptual learning has been limited and there is no extant literature on the effects of perceptual learning and the use of an auditory biofeedback signal with horizontally scrolling format. Past research has tended to focus on RSVP as the mode of text display to investigate the effectiveness of perceptual learning with CVL (Chung, 2011; Pijnacker et al., 2011; Tarita-Nistor et al., 2014). The findings of this study are consistent with previous reports that perceptual learning is beneficial and effective in enhancing reading performance with CVL, with an improvement in reading performance from session one to session three. However, this study did not find a substantial effect of the biofeedback in enhancing the eccentric viewing strategy across sessions. An important consideration here is that this experiment adopted an artificial scotoma paradigm, and the outline of the scotoma is very well defined in comparison to those with a loss of central vision where the scotomas may occur in different sizes and shapes (Schuchard et al., 1999).

Other research (Legge, Ross, Maxwell, et al., 1989) which has examined reading comprehension (the ultimate goal of reading) with dynamic text presentation (i.e., scrolling text) in participants who are normally sighted and participants with low vision has found this method to support effective reading. Additionally, it was concluded that such findings are encouraging for people reading with low vision as good reading comprehension can be obtained even at low reading rates. Although it is important to note that this study conducted by Legge et al., (1989) included participants with a range of different ocular pathologies. This current experiment supports the findings of Legge et al., (1989) where scrolling text was also found to be beneficial for enhancing reading performance and accuracy further supporting and consistent with previous chapters in this thesis (see Chapters 2 and 3) which also found reading with scrolling text, with CVL, to be an effective method for enhancing reading performance. However, a difference between the experiment by Legge et al., (1989) and this study is the comparison of scrolling text with other formats (RSVP and single line static text) using a sample of participants with only an artificial scotoma (no other ocular pathologies). Additionally, this experiment includes the examination of the usefulness of a biofeedback and perceptual learning in improving reading performance and maintenance of eccentric viewing. Nevertheless, the findings of scrolling text enhancing reading performance is consistent with previous work (Legge, Ross, Maxwell, et al., 1989).

In summary, this study has shown that the presence of an auditory biofeedback signal was not useful for enhancing reading performance with each of the text displays (scroll, RSVP and single line static text). Additionally, the presence of a biofeedback was not very effective for training eccentric reading with an artificial scotoma paradigm with static and dynamic text although there was some evidence for some benefits with gist comprehension and partially improving adherence to eccentric viewing. Secondly, perceptual learning was significantly effective in improving reading performance and a significant effect of better adherence to eccentric viewing in session three compared to one with a biofeedback signal. This is the case even with short periods of practice thus perceptual learning appears to be useful and beneficial to implement. Thirdly, reading with scrolling text resulted in better reading performance compared to the RSVP and single line static text presentations. In contrast, the RSVP text display resulted in the poorest reading performance (consistent with Chapters 2 and 3) despite better adherence to the eccentric viewing strategy. This supports research from Rubin & Turano (1994), however, testing reading speed as measured by Rubin & Turano (1994) is not enough as a measure on its own to demonstrate the use of RSVP in the real world. Here, reading comprehension, the ultimate goal of reading, recommended as an important measure by previous research (Rubin, 2013) was measured and indicates that the RSVP format may be less effective for enhancing reading performance with CVL. Finally, from the eye movement analyses (and consistent with chapter 2, Experiment 1b) it is notable that participants do not seem to adopt the eccentric viewing strategy when they are reading with the scrolling text format. Instead, participants tend to use a left to right scanning strategy which consists of looking at the text.

Chapter 5.

Perceptual learning for reading scrolling text with central vision loss

Introduction

Perceptual learning or also referred to as training is defined as; "any relatively permanent and consistent change in the perception of a stimulus array, after practice or experience with this array" (Gibson, 1963, p.29), has shown to be effective for improving performance on a range of visual tasks performed with both central vision (fovea) and peripheral vision (Chung, 2011; Coates & Chung, 2014). The efficacy of perceptual learning in aiding visual performance in the periphery is considered crucial for visual rehabilitation in people with a loss of central vision, where using the peripheral vision is necessary for different tasks such as seeing faces, reading, driving etc. (Coates & Chung, 2014). Reading with a loss of central vision (i.e., with a central scotoma) is slow and challenging (Chung et al., 1998). There are factors such as the size of the visual span (i.e., the number of characters that can be identified in one fixation, a characteristic of visual field) which are associated with the slow reading observed when reading with the peripheral vision (Coates & Chung, 2014). For example, letter identification enforces a perceptual limit on word identification as well as reading rate (Cheong et al., 2007; Legge et al., 2001; Pelli & Tillman, 2008; Yu et al., 2010). It has been proposed that increasing the peripheral visual span (the number of characters that can be identified without any eye movement) may enhance reading rate because more characters can be distinguished resulting in identifying the word (Yu et al., 2010). Chung, Legge and Cheung (2004) demonstrated that the size of the visual span in the peripheral vision, with normally sighted participants, could be increased by perceptual learning this involved testing two groups (one group tested in the upper field first and second group who were tested in the lower field first) who were trained on letter recognition without any feedback with the peripheral vision across four days. Using RSVP, reading rate was measured for single sentences with six different print sizes, alongside visual span. It was suggested that spatial tasks can be enhanced in the peripheral retina using perceptual learning. Therefore, it was proposed that perceptual learning itself may be beneficial for enhancing reading performance in patients with CVL as a result of AMD (Chung et al., 2004; Yu et al., 2010).

People with CVL typically develop an eccentric fixation position beside their scotoma to help them to perform visual tasks including reading (Schuchard, 2005; Timberlake et al., 1987). Perceptual learning may be useful for improving visual performance especially with a loss of central vision where these individuals rely on their peripheral vision for various visual tasks. In the case of reading, studies have shown that patients with low vision, who have a loss of central vision, can be trained using their intact peripheral vision with the caveat of practicing and training for long hours. It has been noted that patients who have CVL may benefit from eccentric viewing training. In a study conducted by Holocomb and Goodrich (1976) it was shown that participants develop a PRL during eccentric viewing training to compensate for their non-functioning fovea. The development of a PRL was proposed to be a crucial component in eccentric viewing training. Jeong & Moon (2011) explored the clinical implications of eccentric viewing training in patients who have a loss of central vision. It was reported that through training (specifically, 30 minutes of daily training, all participants were reassessed after two weeks of eccentric viewing practice), the functional vision of patients and their satisfaction was enhanced.

As discussed, Chung (2011) investigated the usefulness of perceptual learning to improve reading rate using RSVP with individuals who have a loss of central vision as a result of AMD and Stargardt's disease. Participants (n=6, diagnosed with macular degeneration and CVL) were required to practice reading with the RSVP text display with six weekly sessions. The results showed that reading rate for all of the participants with RSVP was enhanced post-training. It was suggested by Chung (2011) that the improvements in reading rate were more likely to be as a result of plasticity of the visual system as well as the continuing sensory impairments rather than participants acquiring a retinal region with better visual capability, or the enhancement in fixation stability. This interpretation was based on these results being consistent with findings which showed increased visual acuity and function through perceptual learning with patients diagnosed with amblyopia (where the patient is unable to reach normal visual acuity) (Holmes & Clarke, 2006). Chung (2011) concluded that perceptual learning may be effective in improving visual performance for patients with CVL more specifically reading rate rather than visual acuity, or fixation stability.

Using the RSVP text display, Tarita-Nistor et al., (2014) investigated perceptual learning for enhancing reading performance in patients who have acquired a loss of central vision (as a result of macular disease) as well as investigating the generalisation of learning to other visual functions. The patients were trained with four sessions in total using the RSVP format. Supporting Chung's (2011) findings, Tarita-Nistor et al., (2014) also found a significant improvement in reading rate from the first to last session and the effects of training with RSVP was generalised to a page reading task, and also binocular visual acuity and fixation stability. However, it is not clear whether these factors were as a result of practicing or whether the findings were as a result of changing the location of the PRL resulting in an improvement in functional capability (Chung, 2020; Tarita-Nistor et al., 2014).

Nguyen, van Landingham, Massof, Rubin, & Ramulu (2014) examined two training techniques for enhancing reading capabilities in patients (n=36) diagnosed with juvenile macular dystrophy (specifically, Stargardt's disease and Best's disease) using an eccentric PRL and low vision aids. The patients were divided into two groups, the first group was trained to read using RSVP and the second group were given 'sensomotoric training', which involves eye movement training by presenting text on the screen using the moving window technique (McConkie & Rayner, 1975, 1976) (where to the reader, a fixed number of characters are present to the left and right of fixation, the text present outside of this window is replaces by other characters or masked) when the text was presented in the middle of the screen, the window moved left to right, thus serving as a guide for eye movements across the text. The total training duration was four weeks with thirty minutes of practice a day, five days a week. Reading performance was measured specifically reading rate during normal page reading before and after training. It was reported that there were no significant differences with the two groups in age, visual acuity and magnification however, individual participants did show improvement. Nguyen et al., (2014) further suggested that both of the training techniques on reading presented a difference in training effect, the RSVP text display decreased fixation stability whereas the sensomotoric training reduced the number of forward saccades. However, Nguyen et al., (2014) reported that patients can adopt these reading techniques that were learnt and apply these in a natural reading scenario.

To date no studies have examined the effects of perceptual learning on reading performance with horizontally scrolling text in people with a loss of central vision. Horizontally scrolling text can be a beneficial way of reading for people with a CVL as it minimises the amount of eye movements necessary to read the text and further reduces challenges in reading found with static text such as perceptual crowding. In Chapter 3, participants with macular degeneration showed better reading performance with scrolling text. Past research has typically focused on reading speed as the main measure of performance typically with RSVP or static text displays. As discussed, reading speed may not be the ideal measure with dynamic text formats. This experiment will investigate whether perceptual learning (i.e., training) over a period of four weeks can aid reading performance (specifically, reading comprehension and reading errors) with scrolling text in people with macular degeneration and a loss of central vision. The findings reported in Chapters 2 and 3 showed that reading performance, (comprehension and accuracy), was significantly better with the scrolling text display than the static and RSVP text displays.

Therefore, the hypotheses of this study are that reading performance will improve with horizontally scrolling text over a period of four weeks compared to static text presentation. Training itself will be performed with scrolling text to investigate whether training or perceptual learning can be generalised to reading with static text. From previous studies (i.e., Chung, 2011; Tarita-Nistor et al., 2014) it was reported that perceptual learning can generalise therefore, it is therefore hypothesised that perceptual learning with scrolling text will be able to be generalised to the static text presentation.

Method

Participants

16 participants with a diagnosis of macular degeneration (mean age = 79.81 years; *SD* = 7.39, mean years since diagnosis = 6.5, *SD* = 4.63) were recruited from the Worthing Macular Society Group from membership of the Macular Society (UK). Near distance reading acuity (measured binocularly using the digital version of the MNREAD Visual Acuity Test) ranged from 0.1 - 1.26 logMAR (mean logMAR = 0.69, *SD* = 0.41). The distance visual acuity was also calculated monocularly (mean logMAR of Right Eye = 0.94, *SD* = 0.27, mean logMAR of Left Eye = 1.05, *SD* = 0.29 and binocularly (mean logMAR = 0.90, *SD* = 0.26). All participants underwent a pre-screening demographic questionnaire to ensure they met the criteria to take-part in the study (see Appendix 2). All participants reported British English as their primary language and were within the normal (unimpaired) range on the Six-item Cognitive Impairment Test (6CIT - Kingshill Version 2000, Dementia screening tool, see Appendix 3). The inclusion criteria to take part within the study consisted of; a diagnosis of macular degeneration (wet, dry or both), CVL in at least one eye, and English as the primary language. The exclusion criteria consisted of; ocular comorbidities and any language, reading or cognitive impairment (see Table 9 for participant information and diagnoses). All participants gave verbal consent and written informed consent prior to participating within the study. The study was reviewed and approved by the College Ethics Committee at Royal Holloway, University of London (Ethics ID 2017/633), and were carried out in line with the tenets of the Declaration of Helsinki (see Appendix 1).

Table 9

Participant information including, age, gender, self-reported diagnosis, reading acuity (near distance visual acuity, logMAR), distance visual acuity for both eyes, left eye and right eye (logMAR) and number of years since diagnosis.

ID	Age	Gender	Reported Diagnosis	logMAR (Reading Acuity)	Distance Visual Acuity (logMAR) Both eyes	Distance Visual Acuity (logMAR) Right eye	Distance Visual Acuity (logMAR) Left eye	Years since onset
1	77	F	Dry Macular Degeneration- Both eyes	1.23	0.92	1.14	1.24	7
2	87	F	Wet Macular Degeneration Both eyes	1.01	0.96	0.92	1.02	3
3	75	F	Dry Macular Degeneration- Both eyes	0.26	1.02	1.12	1.02	8
4	84	F	Dry Macular Degeneration- Both eyes	0.78	0.82	0.92	0.82	10
5	75	F	Dry Macular Degeneration Both eyes	0.46	0.62	0.72	0.82	5
6	81	F	Wet – Left eye Dry – Right eye	0.51	0.66	0.74	0.92	7
7	78	F	Dry Macular Degeneration- Both eyes	0.48	1.02	1.04	1.22	1
8	67	F	Wet Macular Degeneration Both eyes	0.30	0.56	0.54	0.62	4

9	89	F	Wet Macular Degeneration Both eyes	0.31	1.02	1.22	1.46	3
10	67	F	Wet Macular Degeneration Both eyes	1.12	1.28	1.24	1.22	6
11	79	F	Wet Macular Degeneration Both eyes	0.19	0.82	0.92	1.14	5
12	95	F	Dry Macular Degeneration- Both eyes	1.26	1.32	1.36	1.32	18
13	80	F	Dry Macular Degeneration- Both eyes	0.13	1.02	0.84	0.62	15
14	77	F	Dry Macular Degeneration- Both eyes	0.10	0.72	0.74	0.62	1
15	80	F	Wet Macular Degeneration Both eyes	1.04	1.20	1.24	1.22	7
16	86	F	Dry Macular Degeneration- Both eyes	0.78	0.38	0.38	1.48	4

Stimulus and Apparatus

Participants were given standardised passages taken from the Primary YARC battery (Hulme et al., 2009) which also included literal based questions (answers specifically stated in the text, usually one worded answers) and inference based questions (required the participant to elaborate on their answers, showing a higher level of engagement with the passage). All participants were required to read aloud to assess reading accuracy (defined here as reading errors, word substitutions and omissions).

Passages of text were presented on an iPad 2, 2018 (Apple) as white text on a black background in the font Arial. Static text passages were presented using the iBooks application on the iPad and the single line of horizontally scrolling text was presented using the MD_evReader application.

Procedure

The first session consisted of participants completing the digital version of the MNREAD near visual acuity test (measured binocularly). From this, the participants' CPS was obtained – this was doubled and used as the font size for both the scrolling and static text displays in the reading assessment. Participants then completed a short practice trial where they read a short passage of text (taken from BBC News) presented as normal multiline paragraph static text (using iBooks application, see Figure 42a) to familiarise themselves with the application and text presentation. The second passage of text was presented as a single line of horizontally scrolling line of text (using the MD_evReader application, see Figure 42b) (Walker, 2013). During the practice trial of the scrolling text, participants set a suitable and comfortable reading speed. The text presentation speed was set, for each participant, for the remainder of the experiment and was not manipulated further. Participants were then asked to read the standardised YARC passage for each text display followed by questions which was used as the baseline measure of reading comprehension (session 1) for that participant. Participants were also given basic training on using an iPad (if required). Participants were then asked to read a passage taken from 'Emma' by Jane Austin presented as a single line of horizontally scrolling text for 10 minutes per day for a total of four weeks presented as scrolling text using the MDevReader app. They were asked to complete a reading log to monitor their progress and to note down their average time of reading each day to track reading duration (see

Table 10). A follow-up phone call to participants was scheduled around day 3 to ensure they had no problems with the reading task or using the iPad and reading app.

After two weeks (session two), participants were visited and again completed two different passages from the YARC reading test, in the scrolling and static text formats. A third visit was approximately made at the end of the 14-day period, for a final reading assessment, with the scrolling and static text. Participants were also asked to complete a questionnaire (see Appendix 6) to examine their experience of reading scrolling text with the app. Participants completed four weeks of reading practice with scrolling text and had their reading assessed in three separate sessions.

Figure 42

Schematic diagrams of stimulus setup, a) static condition using Apple iBooks, b) scrolling condition, using the MD_evReader application.

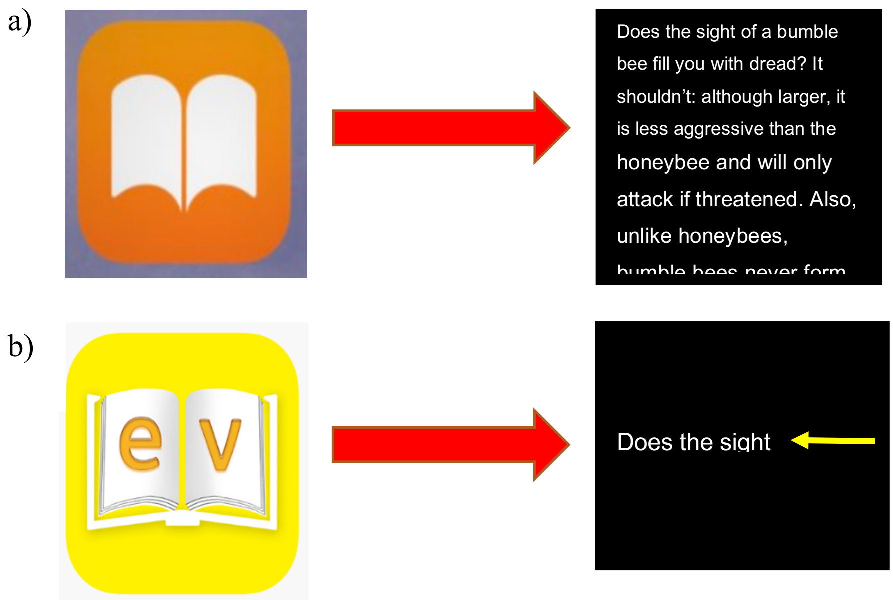


Table 10

Time participants self-reported practicing reading with scrolling text (taken from reading log) after two weeks and after a further two weeks, with the overall average time for all participants. Each participant was asked to spend 10 minutes per day or 2 hours between testing sessions. All participants can be seen to have achieved this and some exceeded it.

ID	Average time spent reading session 1-2	Average time spent reading session 2-3
1	2 hours 20 min	2 hours
2	2 hours 26 min	2 hours 15 min
3	2 hours	2 hours
4	2 hours 10 min	2 hours 30 min
5	2 hours 35 min	2 hours 28 min
6	2 hours 7 min	2 hours
7	2 hours	2 hours 15 min
8	2 hours 20 min	2 hours
9	2 hours	2 hours 10 min
10	2 hours	2 hours 11 min
11	2 hours 40 min	2 hours 10 min
12	2 hours	2 hours
13	3 hours 30 min	2 hours 51 min
14	3 hours 18 min	3 hours 10 min
Overall Average	2 hours 28 min ($SD = 0.43$)	2 hours 20 min ($SD = 0.30$)

Analyses

Statistical analyses were performed using the IBM SPSS. Pearson's r correlations were computed on the amount of time spent practicing between one to two and between two to three and improvement in literal, inferential and overall comprehension. Correlations were conducted to assess if the length of time of practice was a factor in improving reading performance with the scrolling text format. A 3x2 repeated measures ANOVA's (with multiple comparison corrections) examined the effect of session across display types and comprehension scores across sessions for both text displays. Paired sample t-tests were then computed to identify differences between measures. For the subjective user preference questionnaire, all participants (including the two participants who were unable to be tested for session three, n=16) completed the questionnaire feedback.

Results

Reading Comprehension

Figure 43

Reading comprehension (percentages) across all three training sessions (baseline, after 2 weeks and after 4 weeks) for the scrolling and static text displays. Literal comprehension (top left), inferential comprehension scores (top right) and overall total comprehension scores (bottom), with standard error bars.

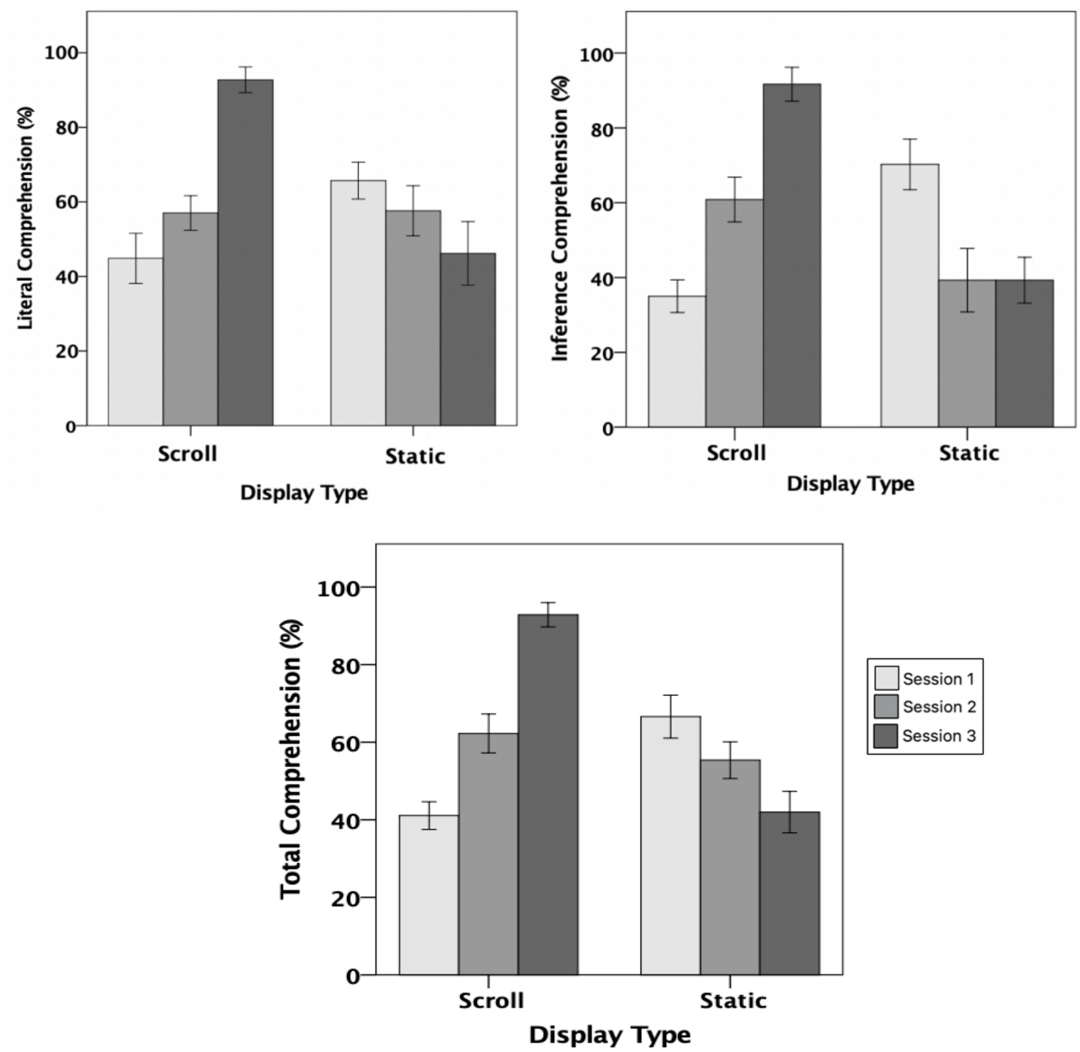


Figure 43 (top left) displays the literal comprehension scores across all three sessions (1-3) for the scrolling and static text display types. It can be seen that there is an overall improvement in comprehension from the initial session to the last session with the scrolling text display only. For the static text display a small decrease is observed from the initial to last session. A 3x2 (three sessions and two text displays) repeated measures ANOVA indicated an overall significant effect of session $F(2,26) = 9.22$, $p = 0.001$, $\eta^2_G = 0.42$ and a significant session and display interaction, $F(2,26) = 15.70$, $p < 0.001$, $\eta^2_G = 0.55$. Paired samples t-tests confirmed significant differences with the scrolling text display for literal comprehension overall from session one ($M = 44.88$, $SE = 6.73$) to session three ($M = 92.74$, $SE = 3.45$), $t(13) = 2.15 = p < 0.001$, and from session two ($M = 60.83$, $SE = 6.01$) to session three, $t(13) = 5.37$, $p < 0.001$, but not from session one to two ($p = 0.051$). For the static text display there was a significant decrease of literal comprehension from session one ($M = 63.93$, $SE = 5.00$) to session three ($M = 46.19$, $SE = 8.52$), $t(13) = 2.35$, $p < 0.05$. The paired samples t-test of session and display indicated that the scrolling text display resulted in significantly better comprehension than the static text presentation ($p = 0.05$) especially during session three ($p < 0.001$).

Figure 43 (top right) show results for inferential comprehension across all three sessions for scrolling and static text displays. A 3x2 repeated measures ANOVA showed an overall significant effect of session with inference based scores $F(2,26) = 30.73$, $p < 0.001$, $\eta^2_G = 0.70$ and an overall significant interaction between session and display type, $F(2,26) = 6.16$, $p < 0.01$.

The paired samples t-test indicated a significant improvement in inferential comprehension with the scrolling text from session one ($M = 35.00$, $SE = 4.37$) to session two ($M = 57.02$, $SE = 4.64$), $t(13) = 4.84$, $p < 0.001$, from session two to session three (M

= 91.67, *SE* = 4.54), $t(13) = 4.96$, $p = 0.001$ and overall improvement from session one to session three, $t(13) = 8.58$, $p < 0.001$. For the static display, there was a decrease in inferential comprehension scores from session one (*M* = 68.45, *SE* = 6.89) to session two (*M* = 39.39, *SE* = 8.49), $t(13) = 3.06$, $p < 0.01$ and overall from session one to session three (*M* = 39.39, *SE* = 6.14), $t(13) = 3.01$, $p = 0.01$, but no significant differences from session two to session three ($p = 1.000$). The paired samples t-test with display type and session indicated for session one, the static text display had significantly higher scores than the scrolling text display, $t(13) = 3.73$, $p < 0.01$ and for session three, the scrolling text had better inference scores than the static text display, $t(13) = 5,81$, $p < 0.001$. There were no significant differences in session two with either text displays ($p = 0.093$).

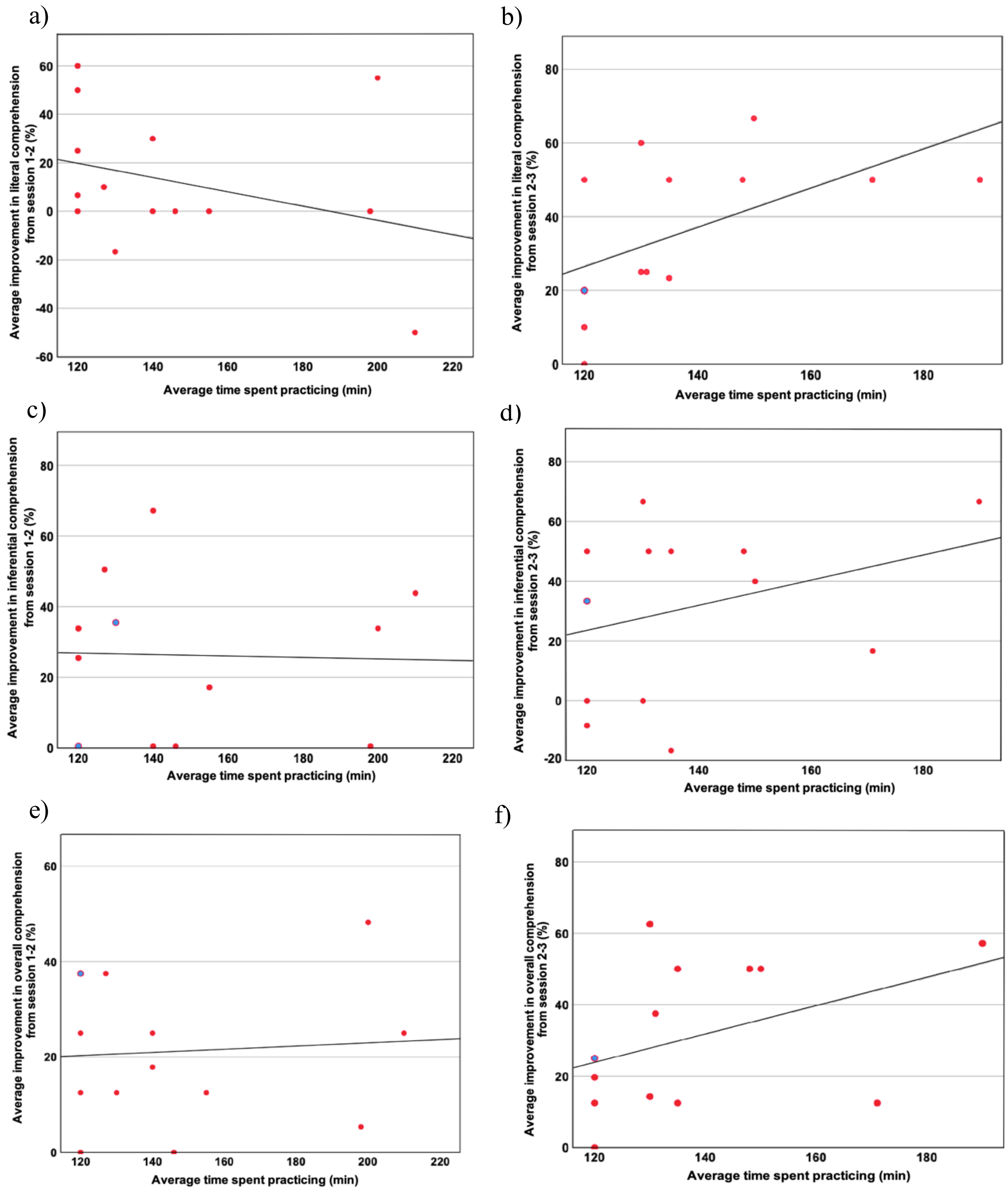
A repeated measures 3x2 ANOVA examined overall comprehension (literal plus inferential), see Figure 43 (bottom), indicated an overall significant effect of session with total comprehension $F(2,26) = 21.981$, $p < 0.001$, $\eta^2_G = 0.63$, an overall significant effect of display type $F(1,13) = 5.80$, $p < 0.05$, $\eta^2_G = 0.31$ and finally an overall interaction of session and display $F(2.26) = 27.74$, $p < 0.001$, $\eta^2_G = 0.68$.

The interaction was examined with paired samples t-tests which indicated an improvement in comprehension with scrolling text from session one (*M* = 41.07, *SE* = 3.57) to session two (*M* = 62.24), $t(13) = 5.25$, $p < 0.001$ and from session two to session three (*M* = 92.86, *SE* = 3.13), $t(13) = 15.09$, $p < 0.001$. For the static text display the paired samples t-test indicated a significant decrease of comprehension performance from session one (*M* = 64.80, *SE* = 5.63) to session three (*M* = 41.96, *SE* = 5.36), $t(13)$ 3.48, $p < 0.01$. There was also a significant difference from session two (*M* = 55.36, *SE* = 4.72) to session three (*M* = 41.96, *SE* = 5.36), $t(13) = 3.33$, $p < 0.01$. There was no significant difference from session one to session two. Paired samples t-tests were also conducted between the text displays. There was a significant difference with overall comprehension in session one with scrolling text and static text where comprehension was better with the static text, $t(13) = 3.70$, $p < 0.01$ however, for session three, overall reading comprehension was significantly better with scrolling text than the static text $t(13) =.8.42$, $p < 0.001$.

A 3x2 repeated measures ANOVA examined reading accuracy (consisting of reading errors, substitutions, insertions and omissions made whilst reading) and showed no significant effects of session ($p = 0.197$), display type ($p = 0.513$) and no interaction between session one ($M = 1.07$, $SE = 0.29$), session two ($M = 0.48$, $SE = 0.13$), session three ($M = 0.44$, $SE = 0.20$) and display ($p = 0.23$).

Figure 44

Regression plots showing average percentage of comprehension improvement from session one to three for a) literal, c) inferential and e) overall and from session two to three for b) literal, d) inferential and f) overall and total time spent practicing reading (minutes). Red circles represent one participant and blue circles represent two participants.



A Pearson's product-moment correlation coefficient was computed to assess the association between the average improvement in literal, inferential and overall (total) comprehension. Figure 44 displays regression plots showing average improvement in comprehension (literal, inferential and total) from sessions 1-2 and 2-3 and the time spent practicing reading with scrolling text, measured in minutes. It is important to note that these show general trends (non-significant) except Figure 44b. Figure 44a shows the improvement with literal comprehension and time spent practicing reading from session 1 to session 2, there is a weak negative association whereby the less time spent practicing reading, the less improvement in literal comprehension. There was a positive correlation between the average improvement in literal comprehension and the average amount of time spent practicing between sessions two and three [$r = 0.53$, $n = 14$, $p = 0.02$]. This graph indicates the opposite pattern, where a significant positive correlation can be observed; the more time spent practicing reading with scrolling text the better the improvement in literal comprehension. Figure 44c displays the improvement in inferential comprehension and time spent practicing reading from sessions 1 to 2. The general non-significant trend here, is a weak negative correlation where the more time participants spend practicing reading with scrolling text, the less improvement in inferential comprehension. However as displayed, there are two participants who do not show this general trend, where they spent longer practicing reading, but did now show improvements in inferential comprehension. Figure 44d displays the improvement in inferential comprehension and duration of time spent practicing from sessions 2 to 3, this graph shows a strong positive correlation where the more time is spent practicing reading, the higher the improvement in inferential comprehension. Finally, Figure 44e, shows the improvement in overall comprehension and time spent practicing reading from sessions 1 to 2. There is a weak positive correlation showing that the more time spent practicing reading the better the improvement in overall comprehension. This is further enhanced in

Figure 44f, from sessions 2 to 3, where a strong positive association is observed between the time spent practicing reading and overall improvement in comprehension.

Questionnaire Feedback

Fourteen (of 16) participants completed the third session and a questionnaire to assess their views on reading using the MDevreader app, in person (n = 14) or, as a result of Covid-19, via a phone call (n = 2). Table 11 displays the questions which were asked to participants, the scale at which the question as scored and the frequency and percentage of responses.

Table 11

Results from the user evaluation questionnaire showing the questions and the median ratings (0–4 Likert scale) and interquartile range (IQR), and yes/no responses.

Question	Median ratings (IQR 25th - 75th percentiles)
How did using the app compare to your usual method of reading? (0 Much worse - 4 Much better)	3 (2.25-4)
Did the app help you to read more easily than usual? (0 Not at all – 4 A lot)	3.5 (2.25-4)
How did you find reading with the app compared to reading normal static text? (0 A lot worse – 4 A lot easier)	4 (3-4)
How likely would you be to continue using the app as a reading aid overall? (0 Very unlikely – 4 Very likely)	4 (2.25-4)
How would you rate the app as a reading aid overall? (0 Very poor – 4 Very good)	4 (2.25-4)
Would an app like this encourage you to read more than now?	Yes = 15, No = 1
Does the app help you read for longer than usual?	Yes = 12, No = 4

75% of respondents reported that the app helped them to read for longer than usual and more easily than usual and that it was better or much better than their usual method of reading, they would be likely or very likely to continue using the app as a reading aid and rated it as good or very good. Furthermore, all but one of the participants (93.8%) agreed that an app like this would encourage them to read more. A Spearman's rank-order correlation was conducted to determine the association between age and responses given for each of the questions asked. For each question asked there were no statistically significant associations ($p > 0.3$), see Table 12.

Table 12

Spearman's Rho Correlation Coefficients between age and response given for each question, and significance level.

Question	Spearman's Rho (r_s)	Significance
How did using the app compare to your usual method of reading? (0 Much worse - 4 Much better)	-0.09	0.74
Did the app help you to read more easily than usual? (0 Not at all – 4 A lot)	0.14	0.60
How did you find reading with the app compared to reading normal static text? (0 A lot worse – 4 A lot easier)	0.21	0.45
How likely would you be to continue using the app as a reading aid overall? (0 Very unlikely – 4 Very likely)	0.17	0.72
How would you rate the app as a reading aid overall? (0 Very poor – 4 Very good)	-0.09	0.76
Would an app like this encourage you to read more than now?	-0.03	0.92
Does the app help you read for longer than usual?	0.24	0.37

Discussion

This study examined perceptual learning (i.e., practice) to improve reading with scrolling text in people with central vision loss (n=14) as a result of macular degeneration. This experiment involved perceptual learning over a period of four weeks and three sessions. Session one was the baseline session, where reading performance was measured before any practice, session two involved participants practicing reading, ten minutes a day, with scrolling text with reading performance being measured after two weeks. Finally, session three included participants practicing reading with scrolling text for a further two weeks, ten minutes a day, with reading performance being measured at the end after four weeks (total of four hours on average) of practicing to read with scrolling text.

The results demonstrated an improvement in reading comprehension for both literal and inferential comprehension measures with scrolling text from the initial baseline session to the final session 4 weeks later. A noteworthy finding was that practice for only 10 minutes per day with scrolling text produced a large improvement in the overall (total) comprehension (approx. 45 to 93%) from session one to session three. This shows that practice (i.e., perceptual learning) is effective and can improve comprehension with scrolling text. By contrast, reading performance with static text decreased from session one to session three. There were no significant differences of reading accuracy from session one to three however, this was expected as there was little room for improvement as participants made considerable low errors in session one.

The generalisation of practice effects from the trained scrolling text to untrained reading with normal static text on a similar display was also examined. The observed improvement in reading performance with scrolling text did not generalise to reading with static text. Results also showed that for the overall reading comprehension there was a weak positive association where the more time spent practicing reading the better the improvement in comprehension from sessions one to two, this association is stronger from sessions two to three. This further enforces that perceptual learning is useful to improve reading performance in people with a loss of central vision.

The subjective user preference questionnaire (n=16) indicated positive user feedback in reading with the scrolling text format. 93.8% of participants felt more encouraged to read now reading with scrolling text, which is the aim of using scrolling text as a reading aid; to help people with macular degeneration read again in a comfortable, easier way. In addition, more than half participants (75%) responded that the app (presenting scrolling text) helped them to read for longer than they usually would read and was easier to read with this app than their normal method of reading. Participants (75%) also responded that they would be likely or very likely to keep using the app as a reading aid and gave it a rating of good or very good. The positive feedback concurs with previous reports of positive feedback from participants with macular degeneration for reading with scrolling text (Bowers et al., 2004; Walker et al., 2016).

This is the first study to examine the potential benefits of perceptual learning with horizontally scrolling text with individuals who have a loss of central vision loss as a result of macular degeneration. Previous research (Chung, 2011; Tarita-Nistor et al., 2014) focused on RSVP as the mode of text presentation and found that enhancement in reading with RSVP that were generalisable to static text. The improvement with scrolling text (with practice) in the present study shows improvement across sessions and there is a decrease with the untrained static text display which emphasises that there is no generalisation between the two text displays. The differences observed in reading comprehension with the static and scrolling text display may be attributed to a variety of factors. During testing participants noted that reading with the static text was particularly challenging. Unlike previous studies, in this study participants were reading on an iPad and were required to move the static text themselves as they were reading, therefore they would often miss out a whole line of text and would lose their place, resulting in them trying to find the correct sentence and the correct place in the text. This suggests that the decrease in comprehension found with the static text may be attributed to participants finding static text challenging potentially resulting in them being less motivated and more tired reading this way. Therefore, ideally practicing reading would be tailored to each individual depending on what the individual could manage (i.e., perhaps some individuals could read longer than others), speed could be measured and altered (for instance, if participants felt they could read faster after two weeks of practice, this could be altered, indicating an improvement in reading).

Previous research which showed a generalisation from practice with RSVP to static text with CVL may reflect a number of factors. For instance, Chung (2011) used a different mode of text display (RSVP) and did not measure reading comprehension and accuracy as the measure of improvement in reading performance. Chung (2011) used reading speed as the measure for improvement in reading performance. Although reading speed may improve over practice it and is a good and useful psychophysical measure, it may not be a reliable measure of reading performance as the main goal of reading is how well the text is understood. Reading comprehension and reading errors were measured to assess reading performance with perceptual learning. Additionally, in Chung's (2011) study, there were a set number of sentences participants read (300 sentences divided into 10 blocks of 30 trials). However, in this study, participants read a book and the amount read was not measured to allow participants to read naturally and not feel pressurised to read a set amount but rather to read 10 minutes a day at a pace they felt comfortable reading at. In addition to this, Tarita-Nistor et al., (2014) also used a different mode of presentation to this study, RSVP, and to assess reading performance the MNREAD chart was used to measure the CPS, maximum reading speed and reading acuity measured at a 40cm viewing distance. Again, in this study reading comprehension using standardised passages and questions were used to assess reading performance. Also, Tarita-Nistor et al., (2014) used a computer to present the reading stimulus whereas in this study an iPad tablet was used which differ in display screen size. An iPad was used here as it was easier for participants to practice reading with scrolling text in their own homes and more of the participants had access to an iPad. Although previous research shows generalisation from RSVP to static text, it is important to consider that in the present study horizontally scrolling text was used and measures of reading comprehension and accuracy were of focus whereas previous research used reading speed. The responses from the subjective user rating questionnaire also suggest that participants generally found it easier to read with scrolling text compared to static text.

In line with previous studies perceptual learning has been shown to be a beneficial method of improving reading performance in participants with macular degeneration. The use of horizontally scrolling text has also been shown to be superior for reading comprehension compared to static text, this was also found in Chapter 3 for the overall reading comprehension however here, reading with scrolling text improved greatly over time.

Chapter 6.

Reading scrolling text with Low Vision: An online study

Introduction

The Wilmer low-vision clinic study reported that 64% of patients diagnosed with wet AMD stated that reading was their biggest challenge (Gill et al., 2013). The majority of people diagnosed with macular degeneration are frequently referred to low-vision (i.e., macular degeneration, cataracts, glaucoma, retinitis pigmentosa, diabetic retinopathy etc.) clinics specifically to aid them with reading. A variety of methods may be demonstrated and administered such as hand-held optical magnifiers, stand magnifiers, closed circuit television (CCTV) devices, telescope lenses and many more. The supply of optical magnifiers has been fundamental and the most frequent therapeutic approach to support and aid those with low vision to optimise their reading aims, especially for patients diagnosed with AMD (Archambault & Colenbrander, 1989). The benefits of using magnification as a reading aid allows the intact peripheral visual areas to resolve the details of the retinal stimulus through magnification, thus bettering reading performance. Although the use of magnifiers has shown improvements in the assessment of visual functioning, the ability to establish a suitable magnification for reading appears to be based upon a trial-and-error method. Despite this, studies have indicated the ability of predicting the required magnification through precise and systematic evaluations. However, this requires the magnification to exceed what has formerly been recommended (Lovie-Kitchin & Whittaker, 1999).

There has been research showing the benefits of low vision aids for instance, Khan et al., (2002) found that in 86% of patients who were prescribed a low vision aid such as a telescope or a magnifier and in 20% of patients of whom were prescribed numerous devices for near distance vision such as bifocals, spectacle magnifiers and stand magnifiers as well as providing training and education to all patients found enhancements in near vision whilst using low vision aids. In addition to this, previous research has also reported that magnification can improve reading performance (measured through reading rate) by up to 200% (Morrice et al., 2017; Nguyen et al., 2009; Rubin, 2013). Commonly, CCTVs tend to have a greater magnification ability compared to other magnification devices, which is reported to increase reading rate when the magnification is used and presented on a bigger screen (Morrice et al., 2017). However, in another study reading rate and duration with the use of CCTV, spectacle reading glasses and illuminated stand magnifiers was examined (Stelmack et al., 1991). It was reported that reading performance was enhanced with CCTV and spectacle lenses in comparison to illuminated stand magnifiers. On the other hand, there were no significant differences when vision aids such as stand illuminated magnifiers and spectacle lenses were compared.

Reading performance may be enhanced with horizontally scrolling text when using reading strategies (i.e., eccentric viewing and steady eye strategy) which may be relatively supported with CCTV aids and stand mounted magnifiers (Ahn & Legge, 1995). In order for effective reading rehabilitation, low vision clinics depend on devices that can measure reading speed accurately and reliably. The addition of standardised passages and content to accurately measure reading performance in patients with low vision have been reported to be a crucial diagnostic tool in low vision research and to compare a variety of low vision reading aids used in visual rehabilitation for patients diagnosed with macular degeneration (Gill et al., 2013). For instance, the reading speed, reading accuracy and patient satisfaction of 27 people with wet AMD with e-readers, Apple iPad and the conventional paper format was compared. It was found that all 27 patients read faster with an Apple iPad when the text size was larger (24point or larger) compared to the conventional paper format. However, participants did read consistently faster with the paper format compared to the eReader. In addition, patients reported that reading with the iPad provided better clarity however, the paper format the easiest to use. It was concluded that digital devices may be particularly effective and useful in visual rehabilitation for those patients attending low vision clinics. For people with AMD, devices or gadgets that are able to provide high contrast and a bigger display screen will be most advantageous for these patients in particular who require a bigger text size to read (Gill et al., 2013).

The advancement of digital technology has resulted in different products being widely accessible and available to access a wide range of growing online digital media. In addition to this, patients are able to access a range of books, articles and magazines with a small percentage (1.5%) of books out of 2 million being available in a bigger print (Gao & Zhou, 2020). The availability of such materials using modern technological devices allows patients with low vision (such as those with macular degeneration) to adjust a variety of features such as changing the degree of brightness, contrast, text size, font size and background colour, image enlargement thus, making reading more comfortable and ideal for people with low vision making them effective low vision aids. With the ageing population electronic books in particular have been forwarded as visual aids and implemented within visual rehabilitation (Crossland et al., 2014; Gill et al., 2013; Lockyer et al., 2005; Nguyen et al., 2011).

In addition to being able to adjust a variety of features (e.g., luminance, contrast sensitivity, brightness, text enlargement, text colour and background colour) with digital technology, text can also be presented in different forms such as horizontally scrolling lines of text (similar to a news ticker) or RSVP (one word presented in sequential order one after the other). Both of these dynamic text formats have been proposed to be potentially beneficial for reading with CVL (Bowers et al., 2004; Fine & Peli, 1995; Harvey & Walker, 2014; Legge, Ross, Luebker, et al., 1989). As a consequence of CVL, people with macular degeneration rely on their intact, preserved peripheral vision, thus they develop or determine a preferred region of their eccentric retina (i.e. preferred retinal loci, PRL) (Fletcher & Schuchard, 1997; von Noorden & Mackensen, 1962; Whittaker et al., 1988). The use of dynamic text presentations such as scrolling lines of text requires the individual to adopt an alternative pattern of oculomotor movements to the typical overlearned eye movement pattern for reading (Rayner, 1998), which has been reported to aid eccentric reading (with the adoption of reading strategies such as eccentric viewing and steady eye strategy) in people with CVL (Fine & Peli, 1995b; Legge, Ross, Luebker, et al., 1989; Rubin & Turano, 1992; Walker et al., 2016).

The adoption of reading strategies such as eccentric viewing involves the reader holding their gaze at an eccentric region at the PRL. This ability may potentially be compromised in people who have macular degeneration (Crossland et al., 2004). A second technique named the steady eye strategy requires the reader to hold gaze in an eccentric region (usually the eccentric viewing location) and moving the text on a page from right to left in front of their eyes, with the aim of decreasing the demands of the eye movement system (Walker et al., 2016). Both of these reading strategies (eccentric viewing and steady eye strategy) may be integrated and further research has shown that these strategies can decrease the challenges with reading (e.g., reading rate, reading comprehension, reading accuracy and in some cases visual acuity (Kasten et al., 2010; Vukicevic & Fitzmaurice, 2005) faced by people with CVL (Nilsson & Nilsson, 1986; Palmer et al., 2009). Horizontally scrolling text (Legge, Ross, Luebker, et al., 1989) as well as RSVP (Rubin & Turano, 1994) may alleviate the challenges experienced when reading eccentrically by reducing the demands of the oculomotor system (for instance, instead of making a succession of saccades and fixations, participants are encouraged to keep the eyes still and fixated and to move the text left to right, thus reducing the number of eye movements necessary to read the text). Previous research has found an increase in reading speed when reading with horizontally scrolling text compared to static text (Legge, Ross, Luebker, et al., 1989) and RSVP text (Fine & Peli, 1995). Therefore, the potential advantages of using digital devices as visual aids such as the ability to alter characteristics and features (i.e., adjusting text size, contrast, brightness, background colour etc.) in conjunction with the ability to present text dynamically such as horizontally scrolling lines of text may be extremely effective in reducing the difficulties in reading encountered by people with CVL as a result of macular degeneration.

Much of the previous literature (Bowers et al., 2004; Harland et al., 1998; Walker, 2013; Walker et al., 2016) has indicated positive feedback from subjective questionnaires of reading with horizontally scrolling lines of text. For instance, Walker, Bryan, Harvey, Riazi, & Anderson (2016) found no significant differences in reading speed with static and horizontally scrolling text (presented on a bespoke app) in a sample of 26 individuals with low vision who were diagnosed with macular degeneration. In addition, reading errors were reduced with the dynamic text presentation than with static text. Despite there being no differences in reading speed, participants reported that they preferred reading with horizontally lines of scrolling text than their usual method for reading. It was concluded that reading performance with scrolling text can be achieved to a level that is equal to reading performance that is achieved with static text. Therefore, such bespoke apps may have great potential as reading aids for people who have CVL as a result of macular degeneration (Walker et al., 2016). Furthermore, other research has also found participants to prefer reading with scrolling text compared to the RSVP text display (Lin & Shieh, 2006). This may be as a result of horizontally scrolling text preserving the parafoveal preview; proposed to be crucial for fluent reading (Schotter et al., 2012). Additionally, scrolling text allows the adoption of the steady eye strategy, as a result of the text scrolling past a fixed viewing region which may dramatically reduce the need to make eye movements; for individuals with CVL, reading rate is positively correlated with the number of fixations that are required for reading, increasing the likelihood of potentially enhancing reading rate compared to static text (Calabrèse et al., 2014).

The purpose of the present study was to obtain structured feedback from people who have low vision including those with AMD of their experience of reading with horizontally scrolling text. The on-line study was performed due to the COVID-19 situation making it difficult for in person testing. The three-stage approach involved an initial questionnaire designed to assess the nature of the visual deficit, a demonstration of reading with a passage of scrolling text, followed by a questionnaire that probed the reading experience with this method. The study used the Ev-platform website to enable people to experience reading a passage of text in the scrolling format. Ev-platform was designed for people with low vision (i.e., macular degeneration) and allows readers to access the news, read email, any text and a selection of books presented as a single line of horizontally scrolling text. Participants with low vision were required to complete three stages of an online survey, stage one; providing demographic information such as age, gender, diagnosis in each eye, years since diagnosis in each eye, stage two; experiencing to read with scrolling text on the Ev-platform website and finally stage three; providing their feedback on their experience of reading with scrolling text as a potential visual reading aid that is fee and accessible. It was hypothesised that reading with scrolling text will result in positive feedback and be a preferred method of reading.

Method

Participants

A total of 29 participants (21 female and 8 male, mean age = 75.24 years, *SD* = 9.26) were recruited through advertisement from the Macular Society (UK) and the Worthing Macular Society group (UK). All participants self-reported a diagnosis (left eye mean number of years since diagnosis = 7.32 years, *SD* = 5.84, right eye mean number of years since diagnosis = 7.48, *SD* = 5.85) of macular degeneration (n=28) and central retinopathy (n=1) (see Table 13 for full participant information). All of the participants gave consent on the survey before taking part. The study was self-certified in line with the guidelines set by the College Ethics Committee at Royal Holloway, University of London.

Table 13

Participant information including ID number of the participant, age range of the participant, gender of the participant, diagnosis reported and the years since onset of the diagnosis for both eyes.

ID	Age range	Gender	Diagnoses	Years since Diagnosis
1	71-80	M	Dry MD – Both eyes	Left Eye – 3 Right – 5
2	60-70	F	Dry MD - Left eye Wet MD – Right eye	Left Eye –1 Right – 1
3	81-89	F	Wet MD- Both eyes	Left Eye – 3 Right – 5
4	60-70	M	Central Retinopathy	Left Eye – 2 Right – 2
5	71-80	M	Wet MD – Right eye	Right Eye - 8
6	71-80	F	Wet MD – Both eyes	Left Eye – 10 Right – 10
7	81-89	F	Wet MD – Both eyes	Left Eye – 8 Right – 6
8	60-70	M	Dry MD – Both eyes	Left Eye – 4 Right – 4
9	71-80	F	Dry MD – Left eye Wet MD – Right eye	Left Eye – 2.5 Right – 2.5
10	71-80	F	Dry MD – Left eye Wet MD – Right eye	Left Eye – 1 Right – 1
11	81-89	F	Dry MD – Right eye	Right – 5

12	71-80	F	Wet MD – Left eye	Left Eye – 6
13	81-89	F	Wet MD – Both eyes	Left Eye – 4 Right – 5
14	60-70	F	Wet MD – Both eyes	Left Eye – 7 Right – 7
15	60-70	F	Wet MD – Both eyes	Left Eye – 15 Right – 9
16	71-80	F	Wet MD – Both eyes	Left Eye – 6 Right – 8
17	71-80	F	Dry MD – Both eyes	Left Eye – 10 Right – 10
18	71-80	F	Wet MD – Left eye Dry MD – Right eye	Left Eye – 2 Right – 2
19	71-80	F	Wet MD – Both eyes	Left Eye – 9 months Right – 3
20	71-80	F	Dry MD – Both eyes	Left Eye – 3 Right – 3
21	71-80	M	Dry MD – Both eyes	Left Eye – 12 Right – 7
22	71-80	F	Wet MD – Both eyes	Left Eye – 10 Right – 10
23	Below 60	F	Wet MD – Both eyes	Left Eye – 10 Right – 20
24	81-89	F	Dry MD - Right eye Wet AMD - Left eye	Left Eye – 20 Right – 20
25	81-89	M	Dry MD – Right eye	Right – 5
26	90+	M	Wet MD – Both eyes	Left Eye – 18 Right – 20
27	71-80	F	Wet MD – Both eyes	Left Eye – 20 Right – 20

28	81-89	F	Dry MD – Both eyes	Left Eye – 3 Right – 3
29	Below 60	M	Wet MD – Both eyes	Left Eye – 9 Right – 8

Stimulus and Apparatus

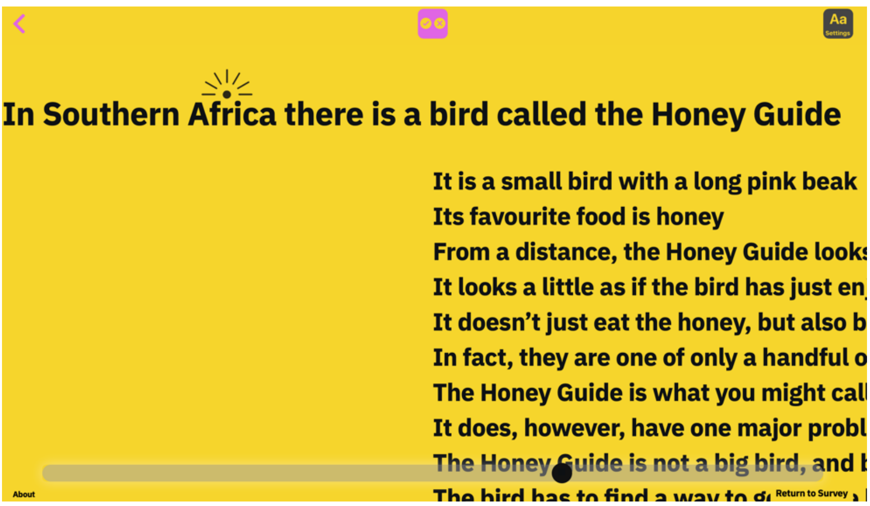
An online survey titled 'Scrolling text Survey with Low Vision' was created using Qualtrics (XM), 2020 (see Appendix 7). An introductory video with audio was created to assist participants with the survey and involved step by step instructions to help them complete the survey. The survey was divided into three sections. The first section required participants to consent to taking part in the survey and to ensure they knew they were able to withdraw or stop the survey at any time, once consenting participants were asked background information including age, gender, eye disorder and diagnosis, how often participants read, participants' normal method for reading, the print size participants feel comfortable reading and finally if participants have read with scrolling text before. The second section of the survey instructed participants to read a passage of scrolling text which was presented on www.ev-platform.org. The passage called 'Honey for me, Honey for you' (see Appendix 5) was taken from the YARC secondary battery (Stothard et al., 2010), with a total of 463 words and 28 sentences. Finally, the third section of the survey involved participants giving feedback on their experience of reading with scrolling text (see Table 14 for full set of questions on the survey).

Procedure

All participants were advised to watch the introductory video before beginning the survey. After reading about the survey, participants were required to give consent prior to taking part. Once completing the first section of the survey, participants were required to read a passage of scrolling text presented on the Ev-platform website (see Figure 45). Once participants were directed to this website, they were instructed to adjust the text size, text colour and background colour to their preference before beginning to read with scrolling text. Participants could adjust the speed of the text by using a slider at the bottom of the screen. Once they finished reading the passage of scrolling text, participants were directed back onto the survey to complete section three; the feedback section (see Table 14 for the feedback questions on the survey).

Figure 45

The passage of text presented on the Ev-platform website displaying the text presented as a single-line of horizontally scrolling text with the slider at the bottom of the image to adjust the speed.



Results

Table 14 displays the questions that were asked in the feedback section of the survey and the frequency and percentage of responses for each question. To examine responses which were evaluating scrolling text as a reading aid, participants' responses were evaluated for these questions as a whole group. These questions included 'How did reading with scrolling text compare to your usual method for reading?', 'How likely would you be to continue using scrolling text as a reading aid?' and finally, 'How would you rate scrolling text as a reading aid overall?'. In the second set of analyses participants were divided into two groups; whether participants had read with scrolling text before (N = 12, group one) or whether they have not read with scrolling text before (N = 17, group two). A mean composite score was computed from three questions which were rated on a rating scale to assess the feedback relating to scrolling text. These questions included 'How did reading with scrolling text compare to your usual method for reading?', 'How likely would you be to continue using scrolling text as a reading aid?' and finally, 'How would you rate scrolling text as a reading aid overall?'. One-way ANOVA's and regressions using SPSS were computed to assess the effect of age, diagnosis and whether participants had at least one training session of eccentric viewing or no training prior of eccentric viewing. Correlations were conducted as this allowed to assess the association of experience of reading with scrolling text with different factors such as if the participants had read with scrolling text before. The reasoning for this was to assess whether responses from participants regarding their experience of reading with scrolling text were correlated with specific factors such as age, being trained in EV and diagnosis. This further would provide an insight into which group of participants scrolling text is beneficial for. The ANOVA's allowed to assess responses from two groups; those who had read with scrolling text before and those who had not, further enabling a thorough analysis of the participants' experience with scrolling text and if this was influenced by those who had experience of scrolling text previously and those who had not.

Table 14

Questions that were asked on the survey and the frequency and percentage of responses from all participants.

Question	Frequency and Percentage
How often do you read at the moment?	Daily (22, 73.3%) Weekly (6, 20%) Very little in a day (1, 3.3%) Rarely (0) Never (0)
What is your normal method of reading?	Book or Newspaper (11, 36.7%) Digital- computer, iPad or Kindle (14, 46.7) Audio (2, 6.7%) Other (2, 6.7)
What print size do you feel comfortable reading with?	Large print size 16pt (10, 33.3%) Standard book size (12-14pt) (5, 16.7%) Newspaper heading size (18-20pt) (4, 13.3%) Large print (22pt +) (10, 33.3%)
Have you read with scrolling text before?	Yes (12, 41.4%) No (17, 58.6%)
How did reading with scrolling text compare to your usual method for reading?	Much worse (1, 3.3%) Slightly worse (3, 10%) About the same (4, 13.3%) Moderately better (11, 36.11%) Much better (10, 33.3%)
Are you aware of the eccentric viewing or steady eye strategy?	Yes, but I have not been trained (5, 17.2%) Yes, and I have had at least one training session (17, 58.6%) No (7, 24.1%)
What colour did you set the background to (if adjusted)?	Did not change (10, 34.5%) White background with black text (10, 34.5%) Grey background with black text (3, 10.3%) Yellow background with black text (5, 17.2%) Black background with white text (1, 3.4%) Black background with grey text (0) Black background with yellow text (0)

Did reading with scrolling text help you to read more easily than usual?	Not at all (6, 20.7) Not sure (6, 20.7%) A lot (17, 58.6%)
How likely would you be to continue using scrolling text as a reading aid?	Extremely likely (9, 31%) Likely (11, 37.9%) Neither likely nor unlikely (3, 10.3%) Unlikely (4, 13.8%) Extremely unlikely (2, 6.9%)
Would a website like this encourage you to read more than now?	Yes (17, 58.6%) No (12, 41.4%)
How would you rate scrolling text as a reading aid overall?	Very poor (1, 3.4%) Poor (3, 10.3%) Ok (4, 13.8%) Good (12, 41.4%) Very good (9, 31%)

Figure 46

Responses (in percentages) given to the feedback relating to scrolling text as a reading aid including a) rating of scrolling text as a reading aid overall, b) likelihood to continue reading with scrolling text as a reading aid and c) how scrolling text compared to the usual method of reading.

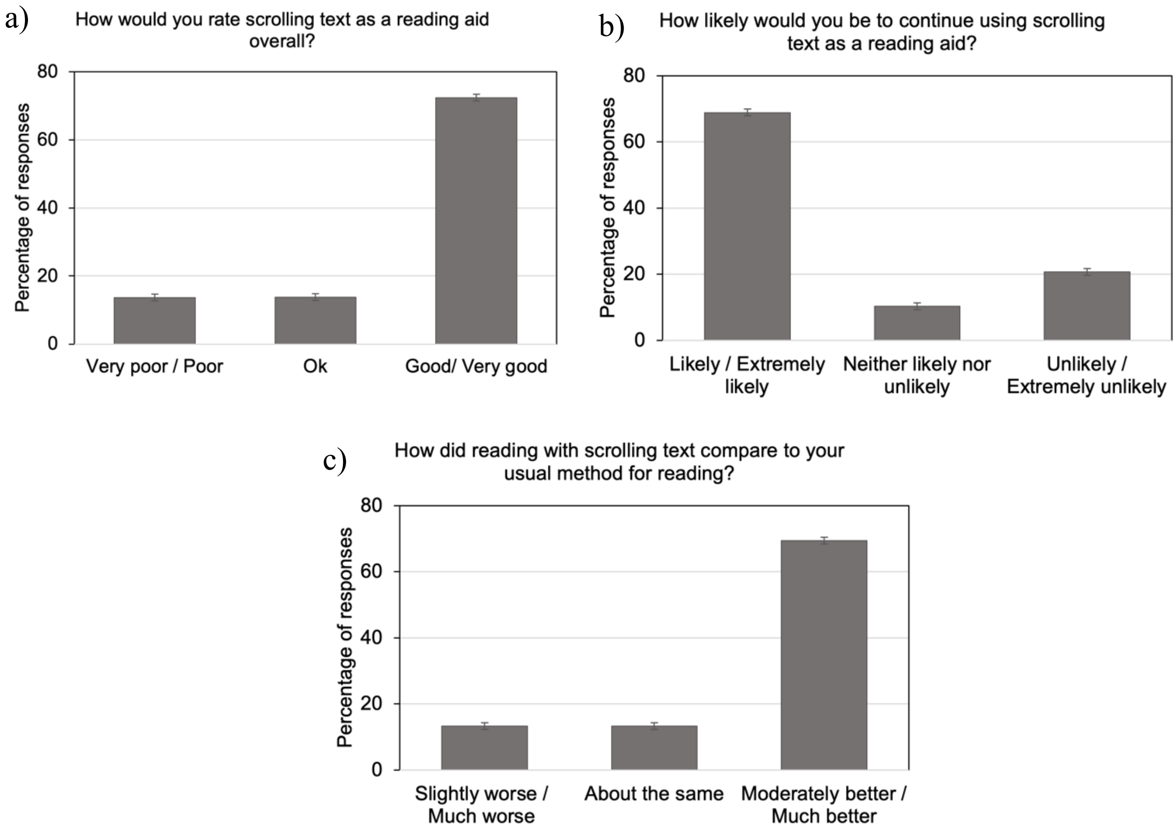


Figure 46a shows positive responses where 72.4% of participants rated scrolling text as a reading aid overall good or very good compared to 13.8% of participants who rated it Ok and 13.7% who rated it as poor or very poor. Thus, the majority of participants rated reading with scrolling text highly. In addition to this, when participants were asked how likely they would to continue to use scrolling text a as reading aid (see Figure 46b), the majority of participants (68.9%) responded likely or extremely likely to continue using scrolling text compared to 10.3% who responded with neither likely nor unlikely and 20.7% whom responses unlikely or extremely unlikely. Finally, the majority of participants (69.41%) rated scrolling text to be a better method of reading compared to their current method compared to 13.3% who rated scrolling text about the same and another 13.3% who rated it as slightly worse or much worse compared to their normal method of reading (see Figure 46c). These results are encouraging and support the use of scrolling text as a potential reading aid for people with macular degeneration.

All participants analysis

A One-way ANOVA and Spearman's Rho correlations were conducted to examine responses to the survey taking into account these factors; age, whether participants had been trained in eccentric viewing or not and diagnosis. A composite mean score (between 0-4) was computed from three questions in the survey to evaluate the feedback for the use of scrolling text. These questions included 'How did reading with scrolling text compare to your usual method for reading?', 'How likely would you be to continue using scrolling text as a reading aid?' and 'How would you rate scrolling text as a reading aid overall?'. Table 15 displays the factor, total number of participants per category, composite mean score and standard deviation, the ANOVA significance level and the correlational significance and p value.

Table 15

Factors including age, training with eccentric viewing and diagnosis, composite mean scores (and standard deviations) comprised of three questions; 'How did reading with scrolling text compare to your usual method for reading?', 'How likely would you be to continue using scrolling text as a reading aid?' and 'How would you rate scrolling text as a reading aid overall?' for all participants (n=29), the ANOVA significance value and the Spearman's Rho correlation value and significance level.

Factor	Composite mean score and standard deviation	ANOVA Significance level	Correlational significance (r_s) and p value
Age	Below 60 (n=2): M = 4.00, SD = 0.00 60-70 (n=5): M = 3.47, SD = 0.99 71-80 (n=14): M = 3.29, SD = 0.94 81-90 (n=7): M = 3.38, SD = 0.71 Over 90 (n=1): M = 4.00, SD = 0.00	0.79	r_s = -0.14 p = 0.47
EV	Trained (n=16): M = 3.21, SD = 0.55 Not trained (n=13): M = 3.58, SD = 1.06	0.23	r_s = 0.12 p = 0.54
Diagnosis	Dry MD (n = 8): M = 3.38, SD = 0.98 Wet MD (n= 15): M = 3.51, SD = 0.87 Both (n=5): M = 3.07, SD = 0.37 Other (n=1): M = 4.00, SD = 0.00	0.68	r_s = -0.13 p = 0.49

Table 15 displays the results of the ANOVA and correlational significance level according to patient age groups, whether patients had been trained in EV before and their diagnosis. The aim here, was to examine whether each of these factors influenced the experience of reading with scrolling text. The number of participants (n) within each category (age, EV and diagnosis) is displayed. Correlations were conducted to assess whether there was an association between each of the factors and the questions asked for example, whether age influenced if participants would continue reading with scrolling text. As presented in Table 15, all results were statistically non-significant.

Table 16

Factors including age, training with eccentric viewing and diagnosis, composite mean scores (and standard deviations) comprised of three questions; 'How did reading with scrolling text compare to your usual method for reading?', 'How likely would you be to continue using scrolling text as a reading aid?' and 'How would you rate scrolling text as a reading aid overall?' for group 1 (read with scrolling text before) and group 2 (not read with scrolling text before), the ANOVA significance value and the Spearman's Rho correlation value and significance level.

Factor	Composite mean score and standard deviation	ANOVA Significance level	Correlational significance (r_s) and *p* value
Age	Group 1: 2.92 (0.51) Group 2: 3.06 (1.14)	0.69	r_s = 1.30 *p* = 0.50
EV	Group 1: 1.75 (0.45) Group 2: 1.41 (0.51)	0.08	r_s = -0.34 *p* = 0.08
Diagnosis	Group 1: 2.08 (0.67) Group 2: 1.94 (0.97)	0.66	r_s = -0.16 *p* = 0.41

All significance levels of the ANOVA and correlations are presented in Table 16. The one-way ANOVA and regression analyses showed no significant effects of age, diagnosis which was divided into dry macular degeneration, wet macular degeneration, both dry and wet macular degeneration and other (central retinopathy) and whether participants had training in eccentric viewing or not. For all participants, the results indicated no significant differences of age, whether participants had been trained in eccentric viewing and their diagnosis on their response to reading with scrolling text. This was also indicated when participants were divided into two groups (read with scrolling text before and not read with scrolling text before. This shows that regardless of whether participants have read with scrolling text or not before, 69.41% of participants (see Figure 46) scored reading with scrolling text to be a better or much better method for reading compared to their usual method of reading without the effect of age, being trained in eccentric viewing or their diagnosis. Additionally, more than half of participants (58.6%) reported that scrolling text helped them to read with much more ease and a website such as Ev-platform (presenting text as horizontally scrolling text) would encourage them to read more than now without the effect of age diagnosis or being trained. Finally, the majority of participants (72.4%) rated scrolling text as a reading aid overall as good or very good (see Figure 46) without age, being trained in eccentric viewing, diagnoses or whether they read with scrolling text before effecting the rating.

Discussion

The aim of this online survey was to assess the wider potential of scrolling text as a reading aid for people with low vision (macular degeneration and central retinopathy; detachment of the central retina resulting in visual loss). There was an overall positive response from participants with their ratings of scrolling text without the effects of age, diagnosis or whether they had been trained in eccentric viewing or read with scrolling text before. For instance, the majority of participants (72.4%) rated scrolling text as a reading aid good or very good. In addition to this, 68.9% of participants responded either very likely or likely to continue to read with scrolling text. The positive responses from this survey demonstrate the effectiveness of scrolling text as a free, accessible reading aid for people with low vision, without age, diagnosis (in this case divided into dry macular degeneration, wet macular degeneration, both dry and wet macular degeneration and retinal maculopathy), being trained in eccentric viewing and whether participants had read with scrolling text, being factors effecting responses. These findings also support the hypothesis set out initially; scrolling text resulted in positive feedback from participants and was a preferred method of reading to their current method.

However, it is important to note that it is unclear as to whether participants within this survey had one eye which was better than the other, thus allowing for more of a normal reading performance. Moreover, it is unclear as to whether participants had a loss of central vision and the visual acuity of each participant, thus only an assumption can be made as a result of being diagnosed with macular degeneration, participants may have a loss of central vision. It should also be noted that only one of the participants in the survey was diagnosed with central retinopathy resulting in vision loss, however this did not affect the overall results of this study. In addition, the majority of participants in this survey were in the age range 71-80 years; resulting in a very narrow age range.

The use of modern technology has potential for reading rehabilitation. For instance, the ability to change a variety of features such as magnifying the text, adjusting the brightness and contrast, text and background colour and may other features is exceptionally beneficial especially for those with low vision such as CVL as a result of macular degeneration (Gill et al., 2013). One crucial benefit of the advancement in technology and devices is the ability to present text dynamically such as horizontally scrolling text and RSVP.

The potential of scrolling text has been investigated with previous research reporting this text format being particularly beneficial for reading speed, comprehension and accuracy and as an overall reading aid for people with central field loss (e.g., Bowers et al., 2004; Legge et al., 1989; Walker, 2013; Walker et al., 2016) and also other visual impairments or disorders namely hemianopia (Koiava et al., 2012). The dynamic text presentation (i.e., moving/scrolling text from right to left) may additionally eliminate the challenge of Troxler fading (Deruaz et al., 2004) (i.e., the disappearance of targets in the periphery as a result of continued stabilisation of gaze) (Bonneh et al., 2014) which has been proposed to be a component in requiring regular saccades (Deruaz et al., 2004). In addition to this, findings from Walker et al. (2016) reported enhanced reading accuracy with scrolling text compared to single line static text. Other previous research has also found faster reading rates by up to 15% with scrolling text compared to static text in people with low vision (Legge, Ross, Luebker, et al., 1989) as well as findings of being able to achieve comprehension levels of those with normal vision if the speed of text was considerably slow (Legge, Ross, Maxwell, et al., 1989). Although other previous studies report either variable or no reading speed gain with scrolling text, it has also received positive feedback through user preference questionnaires as a reading aid with people with low vision compared to other formats such as static and RSVP text displays (Bowers et al., 2004; Harland et al., 1998). In addition to this, in a study conducted by Walker (2013) the majority of participants (who were diagnosed with AMD), favoured reading with scrolling text. This may provide an explanation for the popularity of other devices such as CCTV and stand magnifiers (Ahn & Legge, 1995) which require readers with low vision to manually move the text under the device, thus mimicking a similar movement to that of horizontally scrolling text. Moreover the preference of scrolling text, may also be as a result of enhanced peripheral acuity where stimuli is slightly sharper with moving stimuli compared to static stimuli in the peripheral vision for velocities under 10^{o}/s (Bex et al., 1995; Brown, 1972). This speed was proposed to be an appropriate speed for reading with normal vision (Valsecchi et al., 2013).

The findings from this survey are consistent with previous research which have also reported positive subjective user feedback for reading with scrolling text with low vision and favour for reading with this text format (Bowers et al., 2004; Harland et al., 1998; Walker, 2013; Walker et al., 2016). Obtaining user feedback for reading with scrolling text is important as it provides evidence for the potential benefits (e.g., possibility of users reading more, being better able to use reading strategies such as eccentric viewing and enhanced reading performance) of reading with scrolling text which can be easily accessible and free to use for readers through bespoke apps (e.g., MDev_Reader) (Walker, 2013) and websites such as Ev-platform thus providing another method for reading rehabilitation and enhancing reading for people with CVL as a result of macular degeneration.

Chapter 7.

General Discussion

This thesis involved a thorough investigation of reading performance with static (single line and multiline) and dynamic (horizontally scrolling and RSVP) text formats in people with a loss of central vision. The thesis includes a combination of laboratory-based experiments to evaluate reading performance using a simulated central scotoma controlled by an eye-tracker (allowing for detailed eye movement behaviour measures to be obtained), and comparable studies in people with an actual CVL resulting from macular degeneration. The primary aim was to examine reading performance and eye movement behaviour with static and dynamic text formats with a CVL. The potential of perceptual learning (training) for enhancing reading with static and dynamic text presentations was examined in laboratory-based (artificial scotoma paradigm) study that evaluated the potential of including biofeedback to improve adherence to eccentric viewing with static dynamic text formats. A comparable study evaluated perceptual learning with a sample of people with macular degeneration using an iPad as a training tool. A final on-line study evaluated user experience of reading with the horizontally scrolling text format to evaluate how likely people would use scrolling text as a reading aid for people with macular degeneration.

One of the consequences of macular degeneration, is the loss of central (foveal) vision, that results in great difficulty with reading. Central vison loss results in people using their relatively-intact peripheral vision to read, producing challenges such as poor visual acuity for identifying letters (Chung, 2011). The presentation of text in dynamic formats such as horizontally-scrolling and RSVP may help support reading with CVL by facilitating the use of eccentric viewing and reducing the demands of the oculomotor system (Calabrèse et al., 2014; Harland et al., 1998; Harvey & Walker, 2014; Legge et al., 1985; Legge, Ross, Maxwell, et al., 1989; Rubin & Turano, 1992, 1994; Walker, 2013; Walker et al., 2016). In normal reading a sequence of saccades and fixations are made from left-to-right to identify and process each of the words (Liversedge & Findlay, 2000). However, in people with a CVL directing fixations onto each word is counterproductive as the central scotoma would obscure the word. The use of eccentric viewing; consisting of maintaining fixation at a region located away from the stimulus of interest, using a region of the intact peripheral retina (PRL) to perform visual analysis (Timberlake et al., 1987; Whittaker et al., 1988) in conjunction with scrolling text enables reading whilst the eyes remain away from the text (i.e., PRL, using a peripheral region to inspect text) (Timberlake et al., 1987; Whittaker et al., 1988) which scrolls through the preserved region of the retina (thus decreasing the need to make eye movements to read). In addition, RSVP may also be beneficial based on a similar rationale of reducing the need to make eye movements during reading (Benedetto et al., 2015; Potter, 1984; Potter et al., 1980; Rubin & Turano, 1992). For instance, Rubin & Turano (1992) compared reading performance with the RSVP format and static text in paragraph format in participants with low vision including participants with and without central scotomas. Participants were required to read with both text formats silently and comprehension was measured. Findings showed an increase in reading rate with RSVP although the level of improvement decreased in participants with central scotomas compared to those participants without central scotomas. When comparing eye movements (of four participants) with both formats (RSVP and static text), there was a decrease in the frequency of saccadic eye movements made with RSVP compared to static paragraph text that was thought to be underlying the increase in reading speed, additionally for reading comprehension, participants obtained a average score of at least 75%.

Reading with dynamic text presentation (i.e., scrolling and RSVP text displays) may be beneficial for overcoming difficulties faced by people with CVL when reading with the conventional static text such as navigation through the text and fixation stability (Bellmann et al., 2004; Legge, Ross, Luebker, et al., 1989; Legge, Ross, Maxwell, et al., 1989; Rubin & Turano, 1992, 1994). Patients who acquire CVL (i.e., central scotoma) show an atypical pattern of saccadic eye movements (Rubin & Turano, 1992). Legge, Ross, Luebker, et al., (1989) recorded eye movements when reading scrolling text and observed that the eyes are fixated on a letter and this letter is tracked by the eyes as it scrolls across the display screen through a distance of four-to-five-character spaces, the eyes then make a saccade back to identify a new letter (Buettner et al., 1985; Legge, Rubin, et al., 1985). This pattern of behaviour is also similar when reading static text, but in this case the fixation is a period of smooth leftward pursuit. Legge, Ross, Luebker, et al., (1989) argued that the similarity of the oculomotor behaviour suggests that the spatiotemporal features of retinal images are akin for both text presentations (static and scrolling). Although, it is important to note that when reading with scrolling text, smooth pursuit eye movements must be implemented between the saccades which may be more challenging than making simple fixations (Legge, Ross, Luebker, et al., 1989). Earlier work investigating scrolling text and reading comprehension in both participants with normal vision and participants with low vision (with a variety of pathologies) concluded scrolling text to be an effective method for enhancing reading (Legge, Ross, Maxwell, et al., 1989). In addition, it was concluded that good comprehension is achievable at low reading rates which is encouraging for those with low vision such as CVL (Legge, Ross, Maxwell, et al., 1989). Thus, dynamic text formats, such as horizontally scrolling text, have potential as technological reading aids that can be used on tablets and other electronic devices such as smartphones (Crossland et al., 2014).

The artificial scotoma paradigm is a well-established methodology that uses an eye-tracker to simulate the loss of vision by presenting a gaze-contingent mask (size and shape can be defined by the experimenter) that moves with the eyes. One advantage of this method is that it enables younger participants to be tested in more carefully controlled conditions for longer testing periods than is sometimes possible with an elderly population with actual CVL. This methodology also allows for eye movements to be recorded for in-depth analysis of reading with CVL. By performing laboratory-based studies and similar (as far as possible) studies in people with macular degeneration enables the question of how well laboratory-based findings generalise to people with an actual loss of central vision. If comparable results are obtained, it supports the use of testing typically sighted participants and drawing (limited) conclusions about how elderly people with macular degeneration may perform.

In a first laboratory-based study (Chapter 2 - Experiment 1a) a gaze-contingent artificial scotoma (8-degree) paradigm was used, where participants (normally sighted) were required to read standardised passages of text displayed as a line of horizontally scrolling text, RSVP text, single-line static text and multiple lines of text. The aim was to assess reading performance (speed and comprehension) with an artificial central scotoma with static and dynamic text presentations. It was hypothesised that reading comprehension would be better with the dynamic text presentations compared to the static text presentations as it may facilitate the use of eccentric viewing. Contrary to predictions a significant improvement in reading comprehension was observed with the single line and multiline paragraph formats compared to the horizontally scrolling and RSVP dynamic text displays. The performance with dynamic text presentations (scroll and RSVP) showed a level of performance below what was expected compared to static text compared to previous research (Harvey, Anderson & Walker, 2019; Harvey & Walker, 2014; Legge et al., 1985; Walker, Bryan, Harvey, Riazi, & Anderson, 2016). This experiment used a variable speed manipulation where participants were able to adjust the speed at which text was presented on the screen while reading. This speed ranged from 50-180 wpm with dynamic text presentation and 120-130 wpm with static text presentation. The different speeds for static and dynamic presentations results in confounds and potentially unreliable results. As discussed, horizontally scrolling text enforces a particular maximum reading speed (in this case around 120-130 wpm) because of perceptual blurring and the breakdown of oculomotor tracking behaviour at faster speeds (Slattery & Rayner, 2010). The finding of a reduction in comprehension are at odds with the findings of Walker, Bryan, Harvey, Riazi, & Anderson (2016) who found comprehension (and reading speed) to be better with dynamic text presentation compared to static text presentation with CVL. In the next experiment, speed of both dynamic text presentations was matched to ensure speed was not impacting on comprehension. Furthermore, in this first experiment, participants read silently therefore, it is unknown as to whether they were actually reading the passage or just increasing the speed to finish the experiment quickly. In the next experiment, participants were required to read aloud to ensure all participants were trying and actively taking part in the experiment and reading the text passage, this also allowed to measure reading accuracy (i.e., reading errors made whilst reading aloud). Finally, in the next experiment, participants were encouraged and instructed to adhere to the eccentric viewing strategy with each text presentation allowing for the examination of adherence to this strategy.

Experiment 1b addressed these limitations by adopting a similar methodology, but with the rate of presentation for the dynamic text displays (scrolling text and RSVP) matched to control for the confound of speed between these two formats. The speed of presentation was set for each participant in a practice session at a speed which was comfortable to read at, participants also read with the static text at a speed at which they felt comfortable, and in this case was not manipulated during reading (scrolling speed used as RSVP speed). Reading performance was again assessed (i.e., comprehension and reading accuracy) and participants were required to read aloud enabling errors to be recorded and scored. This also ensured that participants were actively taking part in the experiment and not adjusting the speed faster to get through the experiment for credit points. Adherence to reading with the eccentric viewing strategy was also emphasised and encouraged by the experimenter (who could observe participants fixation on-line during reading on a second monitor) while reading to ensure they were trying to read with their peripheral vision. The analysis of oculomotor behavioural focused on measures of adherence to the eccentric viewing strategy with the single line dynamic and static text presentation formats as these were most comparable and enabled an examination of the oculomotor behaviour used. The ability to hold gaze away from the single words was also examined with RSVP, but in this case a different oculomotor strategy would be employed. It was expected that eccentric viewing and the ability to hold gaze away from the text would be improved with the dynamic text formats. The oculomotor data clearly showed, however, that participants found it difficult to maintain the eccentric viewing strategy (despite being prompted during reading) and instead they used a strategy of left-right horizontal scanning behaviour with static lines and scrolling lines. The two formats that are most directly comparable, in terms of spatial layout, are the single line static and horizontal scrolling formats it was found that both formats showed the typical eye movement behaviour, this is consistent with earlier work (Legge, Ross, Luebker, et al., 1989), however, by contrast to previous work, the present experiment only included a central vision manipulation. It was found that some participants were better able to implement the eccentric viewing strategy with the scrolling text display than the static text display (e.g., see Figures 20 and 21). One possibility is that participants who are typically sighted with little experience of adapting to a CVL and their oculomotor behaviour may differ from that of a person with an actual loss of central vision who has adopted the use of eccentric retinal location for fixation (Crossland et al., 2005). The RSVP text format also resulted in better maintenance of eccentric viewing compared to the other formats. The oculomotor data showed that the eccentric viewing strategy may be difficult to adopt when reading across all formats (dynamic and static text presentations).

An analysis of comprehension found that literal comprehension, that typically consists of one-word answers, was better with the RSVP text display than the scrolling and static text displays. However, inferential comprehension was better with the scrolling text display, as was the overall gist summary (measured through summary points), indicating a greater understanding of the material compared to the static and RSVP text displays. Reading accuracy (i.e., errors made whilst reading) was also better with the scrolling text display compared to the other formats, again indicating more effective reading with this format. The participants' ability to hold their gaze above the text was, however, better with the single word RSVP format, but in this case, comprehension was compromised. This may be due to known limitations with RSVP such as the absence of parafoveal processing effects and visual fatigue when reading with this format (Benedetto et al., 2015).

The second experiment (1b) used an 8-degree artificial scotoma and participants appeared to find reading with the eccentric viewing strategy particularly challenging or may have been poorly motivated to comply with the instruction. There is some evidence (for example, see Figure 21, participants 2, 3, 11 and 13) that some participants who were attempting to adopt the eccentric reading strategy frequently deviated back to looking at the text, performing the pattern of eye movements more typically seen during reading without visual loss. This finding can be related to the case study of AI; a subject who was diagnosed with congenital, extraocular muscular fibrosis, as a consequence leading to ophthalmoplegia. AI was unable to make eye movements and thus compensated by making head movements in a saccadic strategy fashion, demonstrating the strong natural tendency of making saccades (Gilchrist et al., 1997). This is potentially comparable to the findings here and the participants with normal vision found it difficult to overcome the natural strong tendency to fixate on the text and adopt a saccadic scanning strategy (Buchardt et al., 1997). Reading performance did however reveal better comprehension and accuracy with the scrolling text format compared to the static text presentations (single line and multiline formats), while RSVP produced the poorest reading performance (despite having better adherence to eccentric viewing). Nevertheless, these findings of reading performance and adherence to eccentric viewing are consistent and support previous research (Legge, Rubin, et al., 1985) that has shown improvement in adherence to eccentric viewing when reading with RSVP. However, despite the improvement in eccentric viewing, RSVP does not appear to support effective reading (Benedetto et al., 2015; Bouma & De Voogd, 1974). By contrast, readers fixated on the scrolling line of text rather than holding their gaze away from it however this format appears to support better reading. This may be as a result of scrolling text allowing for better sampling of the text with the scanning strategy observed in the eye movement traces in Figure 18 and also because of the known limitations of RSVP that does not support effective comprehension (Benedetto et al., 2015). The majority of previous research focused on reading speed as the main measure of reading performance with macular degeneration. Although reading speed is a good psychophysical measure, it is important to also consider comprehension as this is the ultimate goal of reading. Thus, this chapter builds upon previous work by using reading comprehension and accuracy as the main measures of reading performance with an artificial scotoma paradigm (therefore only including reading with a central scotoma). Additionally, a detailed examination of eye movements (using an artificial scotoma paradigm) is also provided, which may be difficult to obtain with people who have central scotomas, allowing for the possibility to generalise results from the laboratory to individuals with an actual loss of central vision.

Chapter 3 describes a study with similar aims to Experiment 1a and 1b, namely, to examine reading performance with static and scrolling text but in a sample of people with macular degeneration and an actual loss of central vision. Participants were required to read passages of text presented as static single lines or in dynamic formats (RSVP and horizontal-scrolling single lines) presented on an iPad tablet. The main performance measures were reading comprehension (literal and inferential measured using the same standardised test as used in the laboratory experiments) and accuracy. Similar to Experiment 1b, the speed of text presentation was controlled by matching a self-selected reading speed with scrolling text to the approximate rate of word presentation with RSVP. The results showed that the procedure was successful in matching the reading speeds of both dynamic formats thus minimising possible speed-accuracy interpretations. Reading with the scrolling text display resulted in better reading comprehension (for both literal, inferential and summary based comprehension) and the lowest error rates compared to static and RSVP text presentations. By contrast, the RSVP display resulted in poorer reading comprehension (both literal and inferential) and high reading errors compared to both other formats (which is also consistent with Experiment 1b). Thus, these results confirm the effectiveness of reading with scrolling text in supporting reading performance (literal, inferential comprehension and accuracy) consistent with previous reports (Harvey & Walker, 2014) and the laboratory-based studies using an artificial CVL. One difference observed between the laboratory-based study (Experiment 1b) and the findings here (Experiment 2) was that participants with an actual loss of central vision showed better literal comprehension with the scrolling text format. Although all measures of comprehension and accuracy were better with the scrolling format. All studies showed that RSVP produces the highest number of error rates and scrolling text to produce the least number of errors whilst reading. Thus, this suggests participants were better able to read the text with horizontally scrolling text with a higher degree of accuracy compared to the RSVP text display.

It is unclear, however, what the oculomotor strategy the participants with macular degeneration was when reading as eye movements were not be recorded. One possibility is that participants with macular degeneration may have adopted the eccentric viewing strategy as has been found by Crossland et al., (2005) who showed that eccentric viewing can develop spontaneously. It is also possible that participants with macular degeneration read using a similar strategy to the typically sighted observers here and made many fixations onto the text itself. Nevertheless, whichever strategy was used the results from studies from actual and simulated CVL are consistent in showing that scrolling text supports effective reading, while RSVP results in poor understanding. The findings of Experiment 2 are also consistent with previous findings in which scrolling text was found to have higher scores of reading performance (reading comprehension and accuracy) with macular degeneration (Harvey & Walker, 2014). It may be the case that people with an actual loss of central vision are better able to read using the eccentric viewing strategy and they may be more practiced at adopting strategies to compensate for their loss of central vision than those in the laboratory-based studies here. Overall, Chapter 3 builds upon previous research, as the majority of previous research include participants with a variety of eye pathologies. In this Chapter, only people diagnosed with macular degeneration (with a central scotoma) were included. Additionally, as mentioned previously, the main measure of reading performance was reading comprehension and accuracy, rather than reading speed, which is the case with previous research, therefore, this research provides a different measure of reading performance which is considered to be the ultimate goal of reading. Finally, there is limited research on horizontally scrolling text compared with other forms of text presentation with this clinical population, this experiment provides an examination of reading performance (comprehension and accuracy) with different text presentations.

Chapters 4 and 5 report studies designed to examine the effectiveness of perceptual learning (or practice) of reading with static and dynamic text presentation on reading performance (reading comprehension and accuracy). Chapter 4 reported an investigation into perceptual learning and the additional use of an auditory biofeedback signal to improve adherence to eccentric viewing in a laboratory-based study using an eye tracker to simulate the loss of central vision and control the biofeedback auditory signal. The study used the artificial scotoma paradigm (similar to Experiment 1a and 1b) and examined the effectiveness of including a biofeedback auditory warning signal during the training of eccentric reading. The biofeedback signal, in this case a continuous auditory beep if participants deviated away (i.e., less than 4 degrees) from the eccentric viewing region to reinforce the maintenance of reading with eccentric viewing. The eye movement analysis showed that the presence of a biofeedback signal was not as useful in enhancing eccentric viewing and reading comprehension. Although there was evidence for the presence of biofeedback in improving reading accuracy and to an extent the maintenance of eccentric viewing, for instance there were less fixations on the text in session three compared to session one, indicting some improvement in the maintenance of eccentric viewing. There was a stronger effect of perceptual learning on improving and enhancing reading performance with findings also showing better adherence to the eccentric viewing strategy in session three compared to session one. For each measure, reading with scrolling text resulted in consistently better reading performance and demonstrated similar eye movement results to Experiment 1b; participants do not maintain the eccentric viewing strategy and adopt a left-right scanning strategy. Reading with the RSVP text display did result in better maintenance of the eccentric viewing strategy (consistent with Experiment 1b), but comprehension was compromised which is consistent with known factors that make this format unsuitable for effective reading (Benedetto et al., 2015). Nevertheless, perceptual learning did improve comprehension indicating benefits of practice despite the ineffectiveness of biofeedback in improving eccentric viewing. One interpretation is that the adherence to eccentric viewing is less of a critical factor than is practice, as also appeared to be the case in Experiment 1b; this may be because of the challenges of adopting a new oculomotor behaviour (i.e., participants fixating above the text and reading below). The results showed that scrolling text is beneficial for reading with a loss of central vision and may be further enhanced with short amounts of practice to a greater extent than with other forms of text presentation. In addition, there was an improvement of fixation positions from session one to session three, where there were significantly less fixations made on the text in session three. Previous studies have not investigated the potential of combining biofeedback with scrolling text and perceptual learning when reading with a CVL, although there is some research which has found improvements in reading rate with RSVP as a result of perceptual learning (Chung, 2011). The findings from this study emphasise the usefulness and effectiveness of perceptual learning with CVL in improving reading performance.

A subsequent study, reported in Chapter 5, investigated the potential of perceptual learning for reading with scrolling text in participants with actual CVL caused by macular degeneration. This study included 14 participants (with an additional two participants for the feedback questionnaire) who were required to read a book presented in a single line of horizontally scrolling text (like a news ticker) on an Apple iPad. Reading performance (comprehension and accuracy) were measured before practice (session 1), two weeks after practice (session 2) and after 4 weeks of practice (session 3). Static text reading performance (also presented on an iPad with the same font size) was also measured in each session (although no practice was done as this was already a familiar format). Participants spent around four weeks and completed a total of almost 5 hours (4 hours and 48 minutes) on average practicing with scrolling text. The results showed that there was a significant improvement in comprehension from session one (baseline) to the final session (45% - 93%) with scrolling text. By contrast, there was no improvement in reading performance with static text across sessions. Therefore, perceptual learning with scrolling text, was beneficial for people with macular degeneration and improved their reading performance by a significant amount over time. Thus, practicing with scrolling text using a tablet is worth considering as a therapeutic reading aid as the results showed a significant improvement in reading performance. Participants completed a subjective user feedback questionnaire (see Appendix 6) about their experience and responses from participants were overall very positive: 93.8% of participants felt encouraged to read more with scrolling text compared to participants' usual method of reading. A further 75% of participants reported that the MD_evReader application (used to present scrolling text) and perceptual learning training helped them to read for longer and was easier (for instance, more comfortable to read) than their normal method. This user feedback is consistent with previous research which also reported positive feedback obtained from participants with macular degeneration reading with the scrolling text presentation (e.g., Bowers et al., 2004; Walker et al., 2016). One difference with previous research (Chung, 2011; Tarita-Nistor et al., 2014) is that perceptual learning with scrolling text did not generalise to reading static text despite the significant major improvement in reading performance found with scrolling text across each session. The significant improvement in reading performance with the scrolling text display also potentially shows a ceiling effect where participants significantly achieved higher comprehension scores in session three comapred to session one.

Both chapters 4 and 5 investigate the role of perceptual learning (defined here as training to be beneficial for reading with central vision loss) (Chung 2011; Yu et al., 2010). Currently, there is no research which investigates the role of an auditory biofeedback signal coupled with practicing reading with a central scotoma with dynamic text presentation. Chapter 4 incorporates an artificial scotoma paradigm with an auditory biofeedback signal. This is one of the first pieces of research to provide an examination of the use of an auditory feedback signal as a possible way of facilitating reading with an artificial central scotoma with different text displays. Chapter 5 replicates as close as possible Chapter 4, with people who are diagnosed with macular degeneration with a loss of central vision loss. Chapter 4 focused more on the role of perceptual learning, previous research is very limited on perceptual learning with people diagnosed with macular degeneration (with CVL) with dynamic text displays. Thus, both Chapter 4 and 5 provide the foundations for further work to assess in more detail the role of perceptual learning with dynamic text displays for example, by providing longer sessions and measuring reading speed before and after practice to assess if reading speed also improves with perceptual learning.

A further laboratory-based study had been planned to record eye movements of participants with macular degeneration while reading static and scrolling text but had to be revised in light of the COVID-19 pandemic. An alternative on-line study was performed to enable participants to experience reading with scrolling text and report on how they found reading with this method (Chapter 6). The study had three parts: the first asked participants demographic details and about their eye condition. The second part enabled them to experience reading a passage of text presented in horizontally scrolling format and the final part asked them for feedback on how they found reading with this method. This online study (see Appendix 7 for survey questions) included people with low vision (mainly those diagnosed with macular degeneration) with the aim of gaining feedback of their experience of reading with horizontally scrolling text. The inclusion criteria to take part in the survey was to have low vision (mainly aimed at people with macular degeneration however, open to people with low vision). Altogether, 29 participants were included in the data who met the inclusion criteria (28 diagnosed with macular degeneration and one with central retinopathy). The findings indicated overall positive feedback about reading with horizontally scrolling text as a reading aid which is encouraging as it demonstrates the ease at which participants felt they could read when reading with horizontally scrolling text. 70% of the participants reported being able to read better with scrolling text compared to their normal method of reading. Furthermore, 58% of participants reported that reading with scrolling text enabled them to read more easily. The majority of participants also reported that a website (which presents text as horizontally scrolling) would encourage them to read more (demonstrating the benefits of technology and scrolling text). In addition, 72% rated reading with scrolling text as ‘good’ or ‘very good’. These results are encouraging and further illustrate the potential of scrolling text as a reading aid for people with a central vision loss and macular degeneration. The results of this survey are consistent with other reports of a preference for scrolling text as a method for reading in people with a CVL (Bowers et al., 2004; Walker, Bryan, Harvey, Riazi, & Anderson, 2016). There are some limitations of this study: firstly, although participants self-reported being diagnosed with macular degeneration, it is unclear if they did have a loss of central vision. Secondly, there was a narrow age range of the participants, with the majority aged between 71-80 years old (n=14). It is possible therefore, that horizontally scrolling text may be better suited to this age group and it is unclear if it is as useful for other groups (i.e., a younger age group). Nevertheless, this study demonstrates the potential of modern technology and scrolling text as a reading aid for people with macular degeneration. This survey supports previous research and provides further valuable feedback from people with macular degeneration with a loss of central vision loss (previous research tends to include people with a variety of visual impairments). It further provides valuable feedback on current and new digital platforms (in this case the ev_platform) to assess the potential of such platforms as a way to ease reading for people with macular degeneration.

An interesting finding to emerge from this thesis is that people reading horizontally scrolling text with an artificial scotoma were unable to avoid fixating on the text and read while adopting a left-right scanning behaviour (see Figure 18). Although it cannot be confirmed whether participants with macular degeneration were adopting the same or similar strategy, it may be possible that they were adopting the same behaviour. Thus, another possibility is that reading with scrolling text enhanced reading performance however, perhaps not for the reasons posed at the outset of this work. Previous research has proposed that reading with scrolling text (Legge, Ross, Maxwell, et al., 1989) and RSVP formats (Rubin & Turano, 1994) may improve eccentric viewing, and this may be the case for people with an actual loss of central vision. However, the results found within this thesis show that irrespective of adopting eccentric viewing, scrolling text supports more effective reading with a loss of central vision and this could be the focus of further work.

There are many advantages of adopting an artificial scotoma paradigm such as the allowance of testing for longer periods as well as more rigorous testing which may not be suitable for people with actual CVL. The studies in this thesis indicate that the results for reading comprehension measures can be generalised from the laboratory studies with a simulated CVL to individuals with macular degeneration and an actual CVL which is encouraging. For example, one of the consistent findings was of scrolling text consistently producing better reading comprehension compared to other formats, this was the case for both people with an artificial scotoma and CVL. This is encouraging as it provides evidence that findings from the laboratory can be generalised to people with an actual loss of vision which enables stringent testing to be conducted in the laboratory that is unsuitable to do with people who have an actual loss of central vision.

Much of the past research into reading with CVL has focused on reading speed as the main measure for reading performance in people with visual impairments (Harland et al., 1998; Legge, Ross, Maxwell, & Luebker, 1989; Rubin & Turano, 1994). Although this can be a good psychophysical measure, it may not be an appropriate measure for comparing reading performance with different dynamic text formats, as reading speed depends on the rate of presentation of the text, thus imposing a maximum reading speed. Reading comprehension is (largely) independent of reading speed and is the ultimate goal of reading (Watson et al., 1992) and does not have the confound of rate of presentation across different text formats. Furthermore, much of the previous research included participants with low-vision with a range of different eye disorders (e.g., Legge, Ross, Maxwell, et al., 1989) whereas this thesis restricted participants to those with macular degeneration and a CVL only. A limitation of past studies is that it was often not possible to obtain eye movement data from participants with a CVL, so little is known about their oculomotor behaviour during reading. Here, an artificial scotoma paradigm was adopted in some of the studies reported here that enabled detailed eye movement recording to examine the behavioural strategies employed. Although, it is unclear if this behaviour is comparable to people with an actual loss of central vision, the findings were unexpected and of interest. It remains for future comparable studiers of eye movement behaviour in people with macular degeneration to be performed to see if the findings can be generalised. The studies within this thesis include only participants with central vision loss (in at least one eye) and with an artificial central scotoma, ensuring that findings are from this population only and no other eye pathologies. The results consistently indicated that scrolling text is more beneficial for reading comprehension (both literal and inferential) and accuracy with a CVL compared to other forms of text presentation. The feedback received from participants with macular degeneration on reading with scrolling text was also encouraging and emphasises the usefulness and ease for scrolling text as a reading rehabilitation tool for people with CVL.

In summary, this thesis reports the findings of a detailed examination of reading performance with dynamic text presentation (horizontally scrolling text and RSVP) with a loss of central vision. Laboratory-based studies utilised a gaze-contingent artificial scotoma to simulate a CVL in people with normal vision, assessed reading performance (comprehension, accuracy and speed) with dynamic (horizontally scrolling text and RSVP) and static text (single-line static text and multiline paragraph format). Horizontally scrolling text enhanced reading performance compared to static and RSVP text formats with a CVL (potentially as a result of overcoming challenges found when reading with static text) and allowing to better adopt reading strategies such as eccentric viewing and steady eye strategy, resulting in reading with ease. The role of an auditory biofeedback and perceptual learning with scrolling text in the laboratory with an artificial scotoma paradigm. Although biofeedback was not as effective, there were strong effects of perceptual learning for reading performance and adherence to eccentric viewing. The results also supported the use of scrolling text as a reading aid for CVL as performance was again better with this format. An important finding from these studies is that the eye movement data indicated that the implementation of eccentric viewing is especially challenging with static and dynamic formats. Comparable studies of people with an actual loss of central vision (without other eye defects) again showed better reading performance with the scrolling text display compared to other formats and RSVP produced consistently poorer reading performance supporting previous work (e.g., Harvey & Walker, 2014; Legge, Ross, Luebker, et al., 1989; Legge, Ross, Maxwell, et al., 1989). In addition, the benefits of short periods of perceptual learning using an application (i.e., MD_evReader application) which scrolls text horizontally at home illustrates the advantages of scrolling text and tablets as tools for improving reading performance (comprehension and accuracy). Here, training was found to be advantageous with scrolling text, an improvement from 45-93% was found whilst there was no improvement in reading performance with the static text presentation. This provides further support for the use of scrolling text (in this study presented on the MDevReader app) as a reading aid for people with a loss of central vision. Both of these experiments are valuable as they only include participants with CVL which builds upon previous research which include participants with a variety of eye pathologies (e.g., Legge, Ross, Maxwell, et al., 1989; Rubin & Turano, 1994). Finally, the online study with participants with macular degeneration and one participant with central retinopathy showed overall positive feedback of user experience with scrolling text for example, 72% rated scrolling text as a reading aid as good or very good and using this format would encourage more people to read compared to their current method of reading. Again, these are very encouraging responses and demonstrate the use and advantages of scrolling text as a tool to improve reading performance (comprehension and accuracy). In addition, the findings give support to the use of modern technology as a way to help support reading (by improving reading performance) with scrolling text or as a reading aid for people with a loss of central vision as a result of macular degeneration

Limitations and Further work

There are however limitations to the discussed studies. Firstly, it is important to note that all the diagnoses of participants and answers to all eligible criteria questionnaires relied upon self-reports. Therefore, confirmation through diagnostic testing (for example, using a scanner laser ophthalmoscope to confirm a central scotoma) could not be performed. As a result, there is potential for participants to have multiple scotomas or secondary diagnoses without them knowing. Nevertheless, all participants did report having a central scotoma (diagnosed with macular degeneration) with no other eye comorbidities thus they were all eligible to take part. Secondly, it must be acknowledged that all participants who were diagnosed with macular degeneration were self-selected groups. In addition, it is important to consider the participant numbers in studies with participants diagnosed with macular degeneration. Chapter 3 includes a total of 37 participants which is a relatively good number of participants for generalisability and replicability considering the group of participants being tested (diagnosed with a loss of central vision, macular degeneration). In Chapter 5 a total of 14 participants took part, ideally it may have been ideal to test more participants to strengthen generalisability and replicability however, due to the pandemic (COVID-19) and length of time of the study, this was not possible to do so. Another possible limitation is the lack of comparison of comprehension scores in a control population. Testing a control population would have increased the power of the studies and decrease bias by there being a greater comparability and thus having more information regarding the possible differences in response between the clinical group (participants diagnosed with macular degeneration and a loss of central vision and the controls). It is also important to consider that this work involves the relative novelty of reading with horizontally scrolling text compared to other text formats such as RSVP and more typical text presentations (static text). Reading normally is an over-practiced and overlearned oculomotor skill. However, with horizontally scrolling text, this is comparatively less frequently encountered although is seen every day (for example, TV News ticker, train announcement boards etc.). Therefore, the unfamiliarity of reading with horizontally scrolling text may play a significant role in some of the results presented especially with reading with an artificial scotoma. Moreover, all tests conducted within this thesis with people diagnosed with macular degeneration were tested with both eyes (all visual acuity tests and reading). Although this mimics how an individual would read in everyday life, it could be that for some participants their “good eye” (i.e., the eye which is less damaged as a result of the disease) compensated for the “bad eye” (i.e., the eye affected most by macular degeneration), resulting in better reading performance.

Finally, it must also be noted that there are some potential limitations of using white text on a black background (adopted for all studies). It is clear from Chapter 6 that the majority of participants do prefer reading with black text and a white background, perhaps as a result of it being the standard format. Reading with a black background and white text may be more distracting for participants however, in this case this was used to ensure all studies and methodologies were as similar as possible and this format (black background with white text) was favoured during a pilot run. As mentioned previously in this thesis (Chapter 1), the use of a gaze contingent artificial scotoma paradigm may not represent a real scotoma fully. It is important to consider that the central artificial scotoma was a complete circle and predefined (8-degree) and exact for all participants however, in reality scotomas will be different sizes and shapes and vary across participants. Therefore, an artificial scotoma may not be a complete representation of the disease. Secondly, participants who read with an artificial scotoma were reading only during the experiment however, those with a real central scotoma have been adjusting and/or seeing with a scotoma for months and/or years. Nevertheless, the adoption of an artificial central scotoma paradigm allows for stringent testing for long periods within a laboratory which may not be possible with participants who are older with visual deficits.

Further work could address the methodological limitations mentioned throughout this thesis such as including a control group. As mentioned previously, the inclusion of a control group would reduce bias and allow for a clear comparison of the experimental and control group in this case, to assess the benefits of dynamic text presentation with a central scotoma on reading performance. Additionally, a limitation of Chapters 3, 5 and 6 is that there are no eye movements to compare to the laboratory experiments (Chapters 2 and 4). As a result of issues such as calibration and accuracy, the recording of eye movements with people diagnosed with macular degeneration with a central scotoma was not possible. Therefore, it would be interesting for future work to obtain valuable eye movement data from this clinical population to confirm the strategy being adopted whilst reading or to examine the strategy adopted by this clinical group when reading. This would further provide a valuable comparison between laboratory-based experiments and those conducted in real-life, strengthening the findings and generalisability of such research. The participants within this thesis in Chapters 3, 5 and 6 were people diagnosed with macular degeneration with central scotomas, it would be interesting for future work to replicate the experiments with people diagnosed with the juvenile forms of macular degeneration (discussed in Chapter 1). This could provide some valuable information and comparisons of reading performance with different forms of macular degeneration whilst examining the benefits of dynamic text presentation for such clinical populations.

Appendices

Appendix 1. Ethics form

Ethics Review Details

You have chosen to self certify your project.	
Name:	Akthar, Farah (2017)
Email:	PEJT003@ live.rhul.ac.uk
Title of research project or grant:	Reading with dynamic texts
Project type:	Royal Holloway postgraduate research project/grant
Department:	Psychology
Academic supervisor:	Robin Walker
Email address of Academic Supervisor:	robin.walker@ rhul.ac.uk
Funding Body Category:	Charity
Funding Body:	Macular Society
Start date:	16/10/2017
End date:	16/10/2020

Research question summary:

Does reading performance (such as accuracy) improve with dynamic text compared to static text formats?

Will maintaining an eccentric viewing position improve with dynamic text formats - that reduce the demands on the eye movement system?

Research method summary:

Eye tracking methodology will be used in lab-based studies designed to investigate reading performance with static and dynamic text formats. Text will be presented either as static lines, horizontally-scrolling (like a news ticker), or single word rapid serial visual presentation (RSVP) while a video-based Eyelink 1000 system is used to record the participants eye movements. Participants will be undergraduate students and in some situations the eye-tracker will be used to control an artificial visual field deficit (artificial scotoma) that is used to simulate the loss of vision typical of macular degeneration, or a hemianopia following damage to visual cortex. We also aim to include older participants and participants with macular degeneration recruited from the macular society.

The eye-tracker uses two small video-cameras and works by directing invisible (infrared) light onto your eyes, which is then detected by the cameras (the equipment meets both international and EU safety standards). The participants will read the passages of text whilst their head is restrained using a chin-rest. Reading will be performed in short testing periods will lasting around 5-10 minutes to minimise discomfort and the whole testing session will take around 1 hour per participant.

Risks to participants

Does your research involve any of the below?

Children (under the age of 16),

No

Participants with cognitive or physical impairment that may render them unable to give informed consent,

No

Participants who may be vulnerable for personal, emotional, psychological or other reasons,

No

Participants who may become vulnerable as a result of the conduct of the study (e.g. because it raises sensitive issues) or as a result of what is revealed in the study (e.g. criminal behaviour, or behaviour which is culturally or socially questionable),

No

Participants in unequal power relations (e.g. groups that you teach or work with, in which participants may feel coerced or unable to withdraw),

No

Participants who are likely to suffer negative consequences if identified (e.g. professional censure, exposure to stigma or abuse, damage to professional or social standing),

No

Details,

Design and Data

Does your study include any of the following?

Will it be necessary for participants to take part in the study without their knowledge and/or informed consent at the time?,

No

Is there a risk that participants may be or become identifiable?,

No

Is pain or discomfort likely to result from the study?,

Yes

Could the study induce psychological stress or anxiety, or cause harm or negative consequences beyond the risks encountered in normal life?,

No

Does this research require approval from the NHS?,

No

If so what is the NHS Approval number,

Are drugs, placebos or other substances to be administered to the study participants, or will the study involve invasive, intrusive or potentially harmful procedures of any kind?,

No

Will human tissue including blood, saliva, urine, faeces, sperm or eggs be collected or used in the project?,

No

Will the research involve the use of administrative or secure data that requires permission from the appropriate authorities before use?,

No

Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?,

No

Is there a risk that any of the material, data, or outcomes to be used in this study has been derived from ethically-unsound procedures?, No

Details,

Pain or discomfort – eye tracking requires participant to sit with head on chin rest while reading from a computer monitor. Rest periods will be given every 5 minutes and participants will be told if they experience any pain/discomfort to alert the experimenter who will stop the testing and check to see if they are able to carry on after a break. Participants may also experience VDU fatigue, therefore, breaks will be given frequently and as of when requested by participants.

Risks to the Environment / Society

Will the conduct of the research pose risks to the environment, site, society, or artifacts?,

No

Will the research be undertaken on private or government property without permission?,

No

Will geological or sedimentological samples be removed without permission?,

No

Will cultural or archaeological artifacts be removed without permission?,

No

Details,

Risks to Researchers/Institution

Does your research present any of the following risks to researchers or to the institution?

Is there a possibility that the researcher could be placed in a vulnerable situation either emotionally or physically (e.g. by being alone with vulnerable, or potentially aggressive participants, by entering an unsafe environment, or by working in countries in which there is unrest)?,

No

Is the topic of the research sensitive or controversial such that the researcher could be ethically or legally compromised (e.g. as a result of disclosures made during the research)?,

No

Will the research involve the investigation or observation of illegal practices, or the participation in illegal practices?,

No

Could any aspects of the research mean that the University has failed in its duty to care for researchers, participants, or the environment / society?,

No

Is there any reputational risk concerning the source of your funding?,

No

Is there any other ethical issue that may arise during the conduct of this study that could bring the institution into disrepute?,

No

Details,

Declaration

By submitting this form, I declare that the questions above have been answered truthfully and to the best of my knowledge and belief, and that I take full responsibility for these responses. I undertake to observe ethical principles throughout the research project and to report any changes that affect the ethics of the project to the University Research Ethics Committee for review.

Certificate produced for user ID, PEJT003

Date:	18/10/2017 12:10
Signed by:	Akthar, Farah (2017)
Digital Signature:	Farah Akthar
Certificate dated:	10/18/2017 12:46:36 PM
Files uploaded:	Farah Akthar Information Sheet and consent form- Dynamic Texts.docx Final Info Sheet and Consent Form Farah Akthar copy.docx Full-Review-633-2017-10-05-18-59-PEJT003.pdf Full-Review-633-2017-10-18-10-36-PEJT003.pdf Full-Review-633-2017-10-18-10-37-.pdf Full-Review-633-2017-10-18-10-51-.pdf Full-Review-633-2017-10-18-12-45-PEJT003.pdf

Appendix 2. Screening Questionnaire and Demographic Questionnaire (Eligibility Criteria Check-list)

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www.royalholloway.ac.uk/psychology

+44 (0) 1784 443526
PSY-enquiries@rhul.ac.uk

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Telephone Screening Questions

1. Is English your first Language?

Yes ☐ No ☐

If no please state: ____________________

2. Tell me about your vision?

Wet ☐ Dry ☐

Additional Comments:

____

____

3. Is the disease present in one or both eyes?

One Eye ☐ Both Eyes ☐

Additional Comments:

____

____

4. When was the disease diagnosed/condition been present?

____

____

____

____

5. Are there any visual aids you use to help you read?

Glasses ☐ Magnifiers ☐ Light ☐

Other: Only wears glasses for reading, uses magnifiers and light

6. What types of text can you read and roughly at what distance?

Newspaper Headlines ☐ Books ☐

Additional Information:

7. Do you have any other health issues?

Yes ☐ No ☐

If yes: nothing

8. Are there any ocular comorbidities?

Glaucoma ☐ Cataracts ☐ Loss of vision in one eye ☐

Additional Information:

9. Do you have experience using Eccentric Viewing?

Department of Psychology
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+44 (0) 1784 443526
PSY-enquiries@rhul.ac.uk

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Demographic Information and Details about your vision

1. Name:

____

2. Gender

Male ☐ Female ☐

3. What is your age?
17/09/1945

____

4. What is your address (including post code)?

____

5. From the list below, which best describes your ethnic group or background?

White

English/Welsh/Scottish/Northern Irish/British ☐

Irish ☐

Gypsy or Irish Traveler ☐

Any other White background, please describe:

____

____

1

Other ethnic group

Arab ☐

Any other ethnic group, please describe

____

____

6. What is your marital status?

   Single ☐ Married ☐ Widowed ☐ Divorced ☐

   Separated ☐ Other ☐

If other please state: ____

7. What is your highest level of education?

   No schooling completed ☐ Primary school ☐ Secondary school ☐

   Higher Education ☐ Bachelor's Degree ☐ Master's Degree ☐

   Doctorate Degree ☐ Other ☐

If other please state:

____

____

8. Which of the below describes your employment status?

   Employed ☐ Self-Employed ☐ Unemployed ☐

   Unable to work ☐ Retired ☐ Other ☐

9. When were you diagnosed with Macular Degeneration?

____

____

10. Is the condition present in the Right/Left/Both Eyes?

Right ☐ Left ☐ Both Eyes ☐

11. What is the distance you normally read for example: holding a book up to your face?

____

____

Appendix 3: Dementia Screening tool

GIG CYMRU NHS WALES | Bwrdd Iechyd Hywel Dda Health Board

Six Item Cognitive Impairment Test (6CIT)

(6CIT - Kingshill Version 2000, Dementia screening tool)

Patient's Details:	**Date:** **Name of Assessor:**

Question	**Score Range**	**Score**
1. What year is it?	**0 – 4** Correct - 0 points Incorrect – 4 points	
2. What month is it?	**0 – 3** Correct – 0 points Incorrect – 3 points	
3. Give the patient an address phrase to remember with 5 components, eg **John, Smith, 42, High St, Bedford**		
4. About what time is it (within 1 hour)	**0 – 3** Correct – 0 points Incorrect – 3 points	
5. Count backwards from 20-1	**0- 4** Correct - 0 points 1 error – 2 points More than I error – 4 points	
6. Say the months of the year in reverse	**0- 4** Correct - 0 points 1 error – 2 points More than I error – 4 points	
7. Repeat address phrase **John, Smith,** **42, High St,** **Bedford**	**0 – 10** Correct - 0 points 1 error – 2 points 2 errors – 4 points 3 errors – 6 points 4 errors – 8 points All wrong – 10 points	
TOTAL SCORE	**0 – 28**	**/28**

Outcome from Score

0-7 = normal	**Referral not necessary at present**
8- 9 = mild cognitive impairment	**Probably refer**
10-28 = significant cognitive impairment	**Refer**

Appendix 4. Primary YARC passages

Bees

Does the sight of a bumble bee fill you with dread? It shouldn't: although larger, it is less aggressive than the honey bee and will only attack if threatened. Also, unlike honey bees, bumble bees never form an angry swarm because their nests are small. After winter hibernation the queen bee constructs a nest in an old mouse hole or leaf litter or, sometimes, under a shed or large stone. Subsequently, she lays the eggs from which female worker bees develop. While the worker bees collect nectar, the queen continues egg laying. From those eggs laid in late summer, male drones and queen bees develop, the drones' sole purpose in life being to mate with the young queens, thus ensuring the survival of the species. Come the first frosts, the old queen, worker bees and drones die, leaving the young queens to hibernate and await the warmth of spring. We rely on the bumble bee to pollinate our plants, but with buildings replacing their habitats, and pesticides poisoning their food source, man is the greatest threat to their species.

Reptiles

In Australia, the reptiles that are known worldwide as monitor lizards are called goannas. Goannas range in length from 20 centimetres to over 2 metres, but all have the same distinctive shape; a flattened body, long neck with loose skin under the throat, strong legs with long toes and sharp claws, and a long tail. Mostly they are ground dwellers, hunting close to the burrows in which they live, but they are also good tree climbers and strong swimmers. Being carnivores, they eat lizards, snakes, small mammals, birds, and eggs; often swallowing the animals whole. They hunt their prey by tracking and attacking it, or by using their sharp claws to excavate animals and eggs hidden in the ground. Like most lizards, goannas lay eggs, usually in a nest or burrow and between seven to thirty-five eggs at a time. These hatch in eight to ten weeks. Although bulky in appearance, goannas can run swiftly on two legs. They also rear up on two legs when threatened, inflating flaps of skin around their throats, hissing, and lashing out with their power tails.

Shoes

Early shoes similar to sandals might have been created using bark, large leaves and grass, skilfully tied on with vines or reeds. Animal skins may have been cut and hole punched, laced with leather strips and a drawstring strap, and drawn up to produce shoes that enclosed and protected the feet. Sandals worn by Roman soldiers had a criss-crossed lattice and heavily nailed sole. They were ideal for the gruelling marches when conquering European territories. Footwear clearly has very practical origins but, throughout the centuries, it has also been significant as the wearer's social ad fashion statement. In the fourteenth century men wore shoes with long curled toes, the length of which was a clear indicator of a man's wealth and status. They sometimes needed a chain to be attached from the toe to the knee to help them to walk. Modern day trainers or sneakers (so called because the rubberised sole made the shoes stealthy and quiet when walking) became popular in the late nineteenth century, Trainers were worn by athletes until Hollywood picked up the fashion and made them the official uniform of the young and trendy. At the beginning of the twentieth century Converse began manufacturing the first performance basketball shoes which were closely followed by Adi Dassler's hand-made training shoes. To wear footwear with their logos was a signal of just how fashionable we were!

Appendix 5. Secondary YARC passages

The Schoolboy

The ‘Back to School’ signs had been in the shop windows for weeks now. Norman Kirk had always loved the last night of the summer holidays: laying out his clothes for the next morning- shirt, tie, trousers, socks, and finally, the new shoes. It was a relief to get back into the familiar routine after the long, empty summer. He spread margarine into the corners of two white squares of bread and centred a slice of ham, carefully trimming the overhang. Closing the sandwich, he gently sawed a diagonal cut and then, wrapping it in a new sheet of foil, he laid it in the plastic box next to the green apple and the chocolate biscuit. He never tired of his choice of lunch. As he closed the fridge door, he glanced at his watch – nearly nine. A whole hour to spare before bed. Usually there was school work to look at, but not tonight.

Norman turned on the TV. On the first channel ‘Entertainment Tonight’ blared out. A room full of unknown performers sat waiting to be discovered, each hoping that their act would be chosen and propel them to fame and fortune. Norman groaned, entertainment – what a joke – sitting in a darkened room would be more enjoyable. The second channel was showing an old episode of ‘City Detectives’. He’d loved this series when he was younger: the suspense of trying to guess who perpetrated the crime, the satisfaction of being right, the groan of a twisted plot. But there seemed little point watching when he already knew what would happen. He sighed as he scrolled through the channels. He finally settled on a documentary about Britain in his sixties and seventies. Norman smiled as he began to remember his younger days.

Norman Kirk was a quiet man. He lived in an old Victorian redbrick house on a quiet residential street, where long driveways swept up to wide front doors, and tall oak trees lined the footpath, screening the properties from view. He lived close enough to school to be able to walk every day. It took exactly seventeen minutes in good weather. This was to be his last year at the school he had first set foot in six decades ago. It had been September the first, his fifth birthday. His mother used to say, ‘Norman was born ready to go to school!’ School had been his life for sixty years but, in ten months’ time, his life would change forever. People were always asking him what he was going to do when he retired, but he never had an answer. The most thought he had given it had been noting the monthly pension contributions marked on his pay slips. Still, he would have plenty of time to contemplate his future during the long, dark evenings of the autumn-winter term.

Food in the Medieval Times

The idea of medieval man munching on chicken legs and then tossing them over his shoulder to the dogs owes far more to the Hollywood image of Henry VIII than it does to reality! In medieval times, not only would it be frowned upon the feed a dog at the dinner table, but strict codes of etiquette were in force concerning behaviour at mealtimes. In the homes of the wealthy, an usher would stand by with a bowl of water and a towel for the washing of hands, whilst those at the table would be called upon the follow stringent table manners. The food itself would be much more highly spiced than that served today. To a medieval man, modern food would seem very bland. Spices were very expensive and to show that you could afford to flavour your food with them was a real status symbol - consequently, the spicier the food, the greater the host would appear in the sight of his guests! Certain holy days, or feast days, were marked by an abstinence from meat. On these days people were required to eat fish, a great variety of which was available to the rich who often had stew ponds on their estates. These were the repository for freshwater fish caught in nearby rivers. Fish which came from the sea, such as herrings and cod, would have been salted when caught as a means of preserving it for long periods. There were no official vegetarians in the middle ages, but some monastic orders enjoyed a meat-free diet. The most exciting item served up at the feasts of the nobility was the *subtlety.* This was an extravagant dish, frequently made of sugar and fashioned in the shape of an animal or famous Figure, such as St George and the Dragon. These were made to be admired rather than to be eaten. However, this grand choice of dishes was only available to the wealthy. The poor would consume a diet which mainly contained vegetables such as peas, beans, leeks and onions. As a result, although the poor may have eaten meat only when it was available to them, they still found plenty of iron and protein through other means, including the brown bread they ate. The diet of the poor also avoided the large amounts of sugar and salt consumed by the nobility – these, again, were expensive and a means by which to show off. Needless to say, the poor may well have had fewer problems with their teeth than their masters! All in all, a meal for the wealthy was as much a visual feast as a culinary one, but it was the diet eaten by the poor which we would consider to be healthier today.

Honey for you, honey for me

In Southern Africa there is a bird called the Honey Guide. It is a small bird with a long pink beak. Its favourite food is honey. From a distance, the Honey Guide looks drab and brown, but up close you can see a splash of pale yellow on the white chest feathers. It looks a little as if the bird has just enjoyed a meal of golden honey, and been none too careful about its table manners! However, the Honey Guide gets its name not just from the colour of its chest; it is very well adapted to feeding on the contents of beehives. It doesn't just eat the honey, but also bee eggs, larvae, pupae and even beeswax. In fact, they are one of only a handful of birds that can digest wax. The Honey Guide is what you might call a bee specialist. It does, however, have one major problem: Bees sting. The Honey Guide is not a big bird, and bee stings can be very dangerous to it, or even fatal. The bird has to find a way to get at the bees' hive without being badly stung. The Honey Guide has developed a very elegant solution to the problem. It uses humans. The Honey Guide searches around its territory in the African grasslands until it finds a likely-looking beehive. When it has found one, it flies off to find some helpful humans. The bird attracts the humans' attention with a chattering song with short 'peeping' sounds. Once it is sure that it has the people's full attention, it begins to fly off towards the beehive, stopping along the way to check that it's being followed. As it flies, it fans its tail out wide, to make it easier to see. When the bird and its companions reach the hive, the bird calls again to let the humans know that they have arrived. Humans are well equipped to deal with a hive of angry bees. Using smoke, they drug the bees so they won't sting, then break open the hive with a knife to get at the honeycombs. The humans take as much of the honey as they please, but always leave some for the Honey Guide. In this way the bird gets a meal without getting stung, and the people get help finding hard-to-find beehives. There is a saying among some tribes that, if the people are greedy and don't leave a gift of honey for the Honey Guide, the bird will get angry. If that happens, they say, the next time the bird will guide the humans not to a hive, but to a lion, a bull elephant or a poisonous snake. It doesn't pay to be ungrateful for help, even when your helper is a little bird!

Art in a box

Louise Nevelson was born at the end of the 19^{th} century in Russia, an undistinguished Ukrainian child; but died near the end of the 20^{th} century in New York, a celebrated American artist. By the time she passed away in 1988 she had exhibited around the United States, held the position of vice-president of the International Association of Artists, and been included in the 1962 Venice Biennale (still a major contemporary art exhibition). Yet her life had not always been such a success story. She began her career in poverty- poverty that was to prove to be her inspiration. Born Leah Berliawksy in 1899, her family emigrated to America in 1905 and made their home in Maine. When she was 21 she married Charles Nevelson and together they moved to New York City. During her 20s she studied visual and performing arts and was introduced to the work of Marcel Duchamp and Pablo Picasso. After a brief tour of Europe she returned to New York to assist the world famous artist Diego Rivera with his legendary murals. She began her artistic career as a painter, but in the early 1930s she turned to sculpture. However, even though she was gaining valuable experience and learning from some of the period's greatest living artists, her own work was yet to be recognised and she lived on the breadline. As art materials were expensive, each night Nevelson would go out scavenging for anything she could use in her sculptures. She scoured the streets of New York for bits of wood, broken furniture and pieces of ceramics. All of these objects were literally other people's rubbish, but to her they were ideas. She would arrange her *objets trouvés* (found objects) in boxes grouped together, sometimes up to three stories high. She would then paint the final sculpture one colour, frequently black but sometimes white or gold. Nevelson's grouped boxes of vaguely familiar bric-a-brac had about them a sense of mystery which was reflected in their titles- 'Sky Cathedral', 'Silent Music' and 'Sky Gate – New York'. These 'assemblages' or assemblies soon became her trademark. By the 1950s her talent had been acknowledged and her large, abstract sculptures began to earn her major critical recognition. Nevelson staged acclaimed exhibitions throughout the world and received numerous public commissions including a huge steel sculpture in the grounds of Princeton University where other great works by Henry Moore and Picasso can also be found. Her work can also be seen at the Guggenheim Museum, the New York City Museum of Fine Arts and the Fine Arts Museum of San Francisco. Louise Nevelson died in 1988. In the end her poverty led to her invention which in turn led to her being recognised as one of the most important sculptors of the 20th century.

Castaway

A white ensign flying from the heights of Juan Fernandez seemed a curious sight to buccaneer, Woodes Rogers, as he approached the tiny Pacific island. Juan Fernandez was said to be uninhabited so Rogers sent a small boat of armed men to investigate this sign of human life. On making landfall, they were alarmed to be greeted by 'a man cloth'd in goat-skins, who look'd wilder than the first owners of them'. It was 1709 and the man was Alexander Selkirk, a Scottish ship's master, who had been marooned on the island over four years earlier. He was, however, in good health and was able to treat the crewmen to fresh meat, turnips and cabbage in one of his two houses. The story of Selkirk's survival was to become the inspiration for *Robinson Crusoe,* but in many ways the true events of his life are more extraordinary than those in Defoes' novel. Selkirk, like Rogers, had been engaged as a privateer to plunder Spanish shipping along the Pacific coast of South America. He had, however, fallen out with his captain, complaining the vessel he commanded was unseaworthy. When Selkirk went ashore on Juan Fernandez, he was promptly abandoned. However, this was not necessarily such a disaster for Selkirk, for the ship was, in fact, later to sink, as he had predicted. Rogers lists the few items that were left for Selkirk on the island: 'Clothes and bedding. A firelock, some powder, bullets, and tobacco. A hatchet, a knife, a kettle, a Bible and some practical pieces. His mathematical instruments an books.' Selkirk showed great ingenuity with the resources he had. He fashioned knives, for example, from barrel hoops he found on the beach. At first he used the firelock to hunt goats but, when the gunpowder ran out, he simply brought his quarry down 'by speed of foot'. Selkirk was also able to season his food with a black pepper called Malagita, which was very good against 'griping of the guts'. Twice Spanish vessels visited the island, but he feared the Spanish would murder or enslave him. On one occasion, 'they not only shot at him but pursed him into the woods, where he climbed to the top of a tree, at the foot of which they made water, and killed several goats just by, but went off again without discovering him'. After his rescue, Selkirk served three years on Woodes Rogers' flagship as mate. He returned to Britain, three years later, where he met essayist, Richard Steele, who described him thus: 'There was a strong but cheerful seriousness in his look, and a certain disregard to the ordinary things about him, as if he had been sunk in thought. The man frequently bewailed his return to the world, which could not, he said, with all its enjoyments, restore him to the tranquillity of his solitude.'

River Girl

As a young man I walked this road many times. It is the road that connects my small village to the river. Many, many moons ago, my four brothers and I took turns to make this journey. I was stronger then, and faster; the long, dry route did not seem so harsh to me. Setting off at sunrise, I was able to submerge my bucket in the cool fresh water by midday. The journey back inevitably took longer, but I always made it with a smile on my face.

There was a girl you see. She lived in the village adjacent to my own. Each day she came to the river to fetch water as I did. We met often, accidentally at first, and shared glances across the running water. Soon we began meeting deliberately. I found it hard to think of excuses to take turns for my brothers, but she was worth it. We were in love.

One day strangers invaded the village; they carried tools and machines for digging and building. As quickly as they came, they went and in their place they left a large well. We did not need to go to the water anymore; the water came to us. My village rejoiced. I was happy for the villagers, but a peal of sadness resonated in my heart.

For a while I continued to make the journey to the river. The ready supply of water meant that more crops could be grown, and more men were needed to tend them. Opportunities became more and more scarce. I suppose my girl lost hope. I went to look for her whenever I could, but our paths did not cross again. I considered visiting her village but then I heard that her hand had been promised to somebody else; I would not have been welcome.

Time passed and the sun continued to rise and set with a consistency I found comforting. I settled down and raised a family of my own. As my own three children grew, so did my crops flourish and life was happy, most of the time. But soon the light began to fade. My wife has long since seen her final sunset and now I survey the fields alone. My mind wanders back to the days of my youth; I think about my lost love and wonder whether her life has been as rich as mine. That is why I make this journey now. It will undoubtedly be my last.

Appendix 6. Questionnaire used in Chapter 5

User evaluation questionnaire	Median ratings (IQR)
1. How much do you use the eccentric fixation technique when reading? **0 – None of the time, 4 – All of the time**	
2. How much do you use the steady eye technique when reading? **0 – None of the time, 4 – All of the time**	
4. Did you feel that the app helped you to read more easily than usual? **0 – Not at all, 4 – A lot**	
5. How did you find reading with the app compared to reading the static text sentences? **0 – More difficult, 4 – Much easier**	
6. In terms of ease of use, how did using the app compare to your usual method for reading? **0 – More difficult, 4 – Much easier**	
7. In terms of your reading experience, how did using the app compare to your usual method for reading? **0 – Much worse, 4 – Much better**	
8. How likely would you be to use this app as a long-term aid for reading? **0 – Very unlikely, 4 – Very likely**	
9. How would you rate the app as a reading aid overall? **0 – Very poor, 4 – Very good**	
10. Would an app like this encourage you to read more? **Yes or No**	
11. If you feel you would be unlikely to use the app as a long-term aid for reading, what reason would you say most describes why this is? **Cost (Y/N)** **Not easy to use (Y/N)** **Prefer existing visual aids (Y/N)**	
12. What text did you find easiest reading with? RSVP, SCROLL, ML, SL	

Appendix 7. Online survey questions

We would like your feedback and experience of reading with scrolling text that may be a useful method of reading for people with macular degeneration.

This survey has three parts and will take around 15 minutes to complete.

Part 1 will ask you for some background information
Part 2 will allow you to try reading a passage of scrolling text
Part 3 will ask you about your experience of reading with scrolling text

To be entered in a draw to win £50 please provide an email address at the end.

All information provided will be anonymised and used for research and data purposes only.
If you are interested in taking part, please tick the yes option below to provide consent.

I consent to take part in this survey (You can change your mind at any time during the survey):

YES

NO

CONTINUE

Please select your age

- BELOW 60
- 60-70
- 71-80
- 81-89
- 90 or above

Please select your Gender

- Male
- Female

Please describe the nature of your eye condition / diagnosis

- Macular Degeneration
- Stargardt's Disease
- Best's Disease
- OTHER (Please state)

Wet Macular Degeneration

- Left Eye
- Right Eye
- Both

Dry Macular Degeneration

- Left Eye
- Right Eye
- Both

How many years (approximately) have you been diagnosed?

RIGHT EYE

LEFT EYE

How often do you read at the moment?

- Daily
- Weekly
- Very little in a day
- Rarely
- Never

What is your normal method of reading?

- Book or Newspaper
- Digital (Computer, iPad or Kindle)
- Audio
- OTHER (Please state)

What print size do you feel comfortable reading with?

- Standard book size (12-14pt)
- Large print 16pt
- Newspaper Heading size (18-20pt)
- Large print (22pt or more)

Have you read with scrolling text before?

- Yes
- No

GO BACK CONTINUE

How did reading with scrolling text compare to your usual method for reading?

- Much Worse
- Slightly worse
- About the same
- Moderately better
- Much better

Are you aware of eccentric viewing or steady eye strategy?

- Yes but I have NOT been trained
- Yes and I have had at least one training session
- No

What colour did you set the background to (if adjusted)

- Did not change
- White background with black text
- Grey background with black text
- Yellow background with black text
- Black background with white text
- Black background with grey text
- Black background with yellow text

Did reading with scrolling text help you to read more easily than usual?

- Not at all
- Not sure
- A lot

How likely would you be to continue using scrolling text as a reading aid?

- Extremely likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Extremely unlikely

Would an website like this encourage you to read more than now?

- Yes
- No

How would you rate scrolling text as a reading aid overall?

- Very poor
- Poor
- OK
- Good
- Very good

Please click on the arrow in the box to the right to submit your response! Thank you for completing this survey. For more information on techniques that may be useful for reading CLICK HERE. For further information please visit the Macular Society (CLICK HERE to visit).

If you would like to be entered into a draw to win £50 please enter your email address.

[ ]

← →

Abbreviations

AMD – Age-related Macular Degeneration

ANOVA – Analysis of Variance

AREDS – Age-related Eye Disease

cm – Centimetres

CPS – Critical Print Size

CVL – Central Vision Loss

IQR – Interquartile Range

LGN – Lateral Geniculate Nucleus

M – Mean

mm – Millimetres

ms – Milliseconds

PRL – Preferred Retinal Locus

RHUL – Royal Holloway, University of London

ROI – Region of Interest

RPE – Retinal Pigment Epithelium

RSVP – Rapid Serial Visual Presentation

SD – Standard Deviation

SE – Standard Error

SPSS – Statistical Package for the Social Sciences

VEGF – Vascular Endothelial Growth Factor

WPM – Words per minute

YARC – York Assessment of Reading Comprehension

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