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**A Comparison of the Eye Movement  
Patterns Used for Comprehension and  
Scanning Reading Techniques**

A thesis  
submitted in fulfilment  
of the requirements for the degree  
of  
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at  
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## **Abstract**

Two techniques that can be used when reading are scanning the text for particular information and reading for full comprehension. These two reading techniques may be achieved using different eye movements. This thesis explores the use of various eye movement measures for the purpose of comparing reading comprehension and scanning techniques. Eye tracking technology is used to detect the eye movements of readers while they read a section of text requiring them to scan the text for information or read for comprehension. Eye movement measures proved to be successful in differentiating between reading techniques. The eye movements involved in reading for comprehension were found to be different from the eye movements involved in scanning the text for information, as demonstrated by the differences in multiple eye movement measures between the two reading conditions. Notably large differences between the eye movements made by readers under the same reading conditions highlighted the highly variable and individual-specific nature of reading behaviour. The findings relating to the eye movements that are used for different reading techniques may be beneficial for people who seek to improve their reading skills. Eye movements could possibly become a useful part of reading instruction. These results may also be used as norms against which the eye movements of those with abnormal reading patterns could be compared for the purpose of diagnosis of reading difficulties.

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# Table of Contents

Abstract.....	ii
Acknowledgements.....	iii
Table of Contents.....	iv
Table of Figures.....	vi
Introduction .....	1
Eye Movements Involved in Reading .....	2
Tracking Eye Movement .....	4
Methods of Detecting Differences in Reading Techniques.....	7
Reading Techniques: Comprehension and Scanning .....	11
Factors Affecting Reading Behaviour .....	15
Comparison with Existing Research .....	20
Applications .....	22
The Present Study.....	25
Hypotheses .....	26
Method Section.....	27
Participants .....	27
Apparatus .....	27
Materials.....	28
Procedure.....	31
Experiment Design.....	31
Data Analysis .....	32
Results .....	39

Fixation Duration .....	39
Total Fixation Duration .....	40
Total Reading Time .....	41
Forward Jump Distance .....	42
Number of Backward Jumps .....	43
Previous Line Jumps .....	44
Number of Fixations .....	45
Velocity .....	46
Individual differences .....	47
Questionnaire Results .....	49
Influence of Other Factors on Eye Movement Results .....	50
Discussion .....	52
Main Findings .....	52
Self-Report Questionnaire .....	56
Individual Differences .....	57
Applications of the Findings .....	59
Limitations .....	60
Future Research .....	63
Conclusions .....	66
References .....	67
Appendices .....	73

# Table of Figures

Figure 1 .....	29
Figure 2 .....	30
Figure 3 .....	34
Figure 4 .....	34
Figure 5 .....	35
Figure 6 .....	36
Figure 7 .....	37
Figure 8 .....	39
Figure 9 .....	40
Figure 10 .....	41
Figure 11 .....	42
Figure 12 .....	43
Figure 13 .....	44
Figure 14 .....	45
Figure 15 .....	46
Figure 16 .....	48
Figure 17 .....	49
Figure 18 .....	51



# Introduction

In daily life, countless situations arise in which a person must read written text. People may gather information about their environment through reading a road sign, learn new skills through reading a manual, communicate with others through reading an e-mail, be aware of rules through reading a contract, read for their own enjoyment with a novel, or many other reasons. The basic process of reading is made possible by the movement of the eyes across text, through which the brain perceives information that is then assigned meaning.

There are various circumstances in which a person may wish to improve their reading skills and their use of different reading techniques. These could include students who seek to improve their studying skills, people who are learning English as a second language, children who are learning to read for the first time, and people who have abnormal reading behaviour due to reading difficulties such as dyslexia. Having knowledge of the eye movements that can be used to achieve different reading techniques would be valuable for the people in these situations.

There is more than one technique for reading. This thesis will compare reading for careful comprehension of a topic to reading for the purpose of searching for a particular piece of information, also known as scanning. Both of these are reading skills which may be used to gather and process information, learn new things, study and understand. How are the eye movements that are used to achieve these reading techniques different? Is it possible to successfully determine the difference between comprehension and scanning reading techniques based on the eye movements that are used for each technique?

## **Eye Movements Involved in Reading**

Despite there being different reading techniques that it is possible for a reader to use, all reading involves common basic eye movements and processing. All forms of reading include both saccades, which are rapid movements of the eyes from one area of the text to another, and fixations, which are the pauses that the eye makes on an area of the text (Rayner, Chace, Slattery & Ashby, 2006). Kapoula (2012, p.2) states that in normal reading of a passage of text, “90% of reading time is devoted to fixations, while saccades take only 10% of the time; the majority of saccades are made from left to right and have a mean length of seven to nine characters... About 12% of the saccades are in the opposite direction”. Kleigl, Nuthmann & Engbert (2006, p.12) further explain, “...Reading proceeds as an alternating sequence of fixations (lasting 150 to 300 milliseconds) and saccades (30 milliseconds). Information uptake is largely restricted to fixations.”

There are various models that attempt to explain the way in which eye movements function and enable words to be processed. An early account of the processing of text was provided by Just and Carpenter (1980), which explained that where the eye fixates, at the central focus point called the fovea, processing of the fixated text is taking place. The reader fixates on a word for as long as is required for the comprehension of its meaning, before making a saccade to the next fixation point. The immediacy assumption and the eye-mind assumption were proposed by Just and Carpenter (1980). These are, respectively, that the presently fixated word is processed and interpreted immediately once it is fixated upon, and that the eye remains fixated upon until this interpretation process is completed. It could therefore be assumed that the process of interpreting a word lasts for the duration of time that it is being fixated on, and that this length may be an indication of the difficulty or cognitive load required to interpret the word. This basic account of

reading eye movement has been cited and built on in subsequent reading research, but has also been disputed by some. Kliegl et al. (2006) discovered evidence that the brain is able to process more than one word in parallel, which may involve the word presently fixated on being processed at the same time as previously fixated words, or upcoming words in the text which are already within the parafoveal region, slightly outside the central point of focus. This new research, moving beyond the earlier more simplistic theory by Just and Carpenter (1980), highlighted the complexity of the eye movements that make reading possible and the cognitive processing which is taking place as the eyes make these movements.

Engbert, Nuthmann, Richter, and Kliegl (2005) explain the process of all eye movement that takes place during reading, building on an existing SWIFT model of eye movement (Engbert et al., 2002, as cited in Engbert et al. 2005). This is a model that aims to represent how the process of reading takes place in the brain. Similar to the early model proposed by Just and Carpenter (1980), the SWIFT model focuses on the relationship between word processing and eye movement generation. Words are processed when they are at the centre of the visual field, or fovea. Saccades move the eyes to enable the chosen word to be focused on at the centre of the fovea. Engbert et al. (2005) explain that there are two types of cells in the brainstem which are involved in eye movement: omnipause cells, which fire only during fixations and are therefore only responsible for providing information on the temporal quality of saccades; and burst cells, which fire during the length of a saccade and are therefore only responsible for providing information on the spatial quality of saccades. Together, omnipause and burst cells provide information on where and when a saccade is taking place. This model allows for saccades to be made in any direction, not solely forward to the next word, and in parallel, not necessarily in a serial left to right pattern.

Heinzle, Hepp and Martin (2012) also aimed to create a model of reading eye movements that represents how the process of reading takes place in the brain. This computational model was based on the frontal eye field area of the brain. Unlike the SWIFT model (Engbert et al., 2015), this model assumes a serial pattern of processing from left to right, where one word is fully processed before the next is focused on. Heinzle et al. (2012) explain that two processes begin simultaneously once a word is at the centre of the fovea: motor build-up and word processing. If motor build-up is completed faster than word processing, a saccade is made to the next word to be read. If word processing is completed faster than motor build-up, the next saccade is skipped, resulting in the next word being skipped and another saccade being made to a further location. This process would lead to the scanning of text rather than reading fully. At the end of the line of text where there are no words left to be read, a saccade is then made to the left at the beginning of the line. The authors acknowledge that this model is a highly simplified version of the real process of reading undertaken by the brain.

Although these models of reading are relatively different and focus on separate areas of the brain, they all involve as integral components both the processing of words, and the movements that are made by the eyes to achieve this processing. In other words, these models demonstrate that at the basic level, reading is understood to occur when the eyes make movements towards words in order to process their meaning, although the specific brain functions involved are yet to be fully understood.

### **Tracking Eye Movement**

In order to discover whether different reading techniques involve differences in the eye movements used to achieve them, eye movements must be measured. In

modern times, each eye movement made by a reader is able to be captured using eye tracking equipment. The present experiment will involve the use of eye tracking technology to determine the eye movements that are made during the process of reading for comprehension and scanning the text.

As noted by Henderson and Luke (2014, p. 1319), using an eye tracker while reading can “generate a relatively large amount of data in a relatively small amount of time given that each fixation or saccade is a potential data point”. This enables the researcher to gain a large amount of information regarding the direction and duration of the reader’s eye movements, and manipulate the stimulus that is being read to trigger different reading techniques in order to record the differences in these movements.

According to Mohamed, Perreira Da Silva and Courboulay (2007), The first eye tracking studies took place in the 1940’s, the majority of which were for military purposes. One of the first of these studies was undertaken by Fitts, Jones and Milton in 1947 (as cited in Mohamed et al., 2007), who researched the eye movement patterns of pilots while carrying out flying tasks. This research originally led to the assumptions that the frequency of fixations made on a particular instrument related to the importance of that instrument to the participant, and that the length of fixations made on a particular instrument related to the difficulty experienced by the participant in using that particular instrument. These assumptions link to the Eye-Mind Hypothesis of Just and Carpenter (1980). In the 1980’s, the rapid development of computer technology enabled the growth of the possibilities and accuracy of eye tracking technology.

Earlier eye tracking technology tended to require head-mounted eye trackers with electrodes attached to the participant (Mohamed et al., 2007) which was more invasive than the technology that is used today and may have led to participants’

natural behaviour being compromised by strong observer effects. The present study aims to be as non-invasive as possible when measuring participants' reading behaviour using the eye tracker, in order to simulate a natural, true to life reading environment for the experiment. The ideal situation would be for the participant to forget that they are in an experimental environment so that their reading behaviour is not different from how it would be during day-to-day reading activities. This is less likely when using invasive technology.

The most common method of eye tracking (though not all eye tracking technology uses this method) involves infrared light being reflected from the cornea of the eye, allowing the position of the pupil to be tracked in relation to the display that is being looked at by the participant, and determining where on the display the participant is looking (Mohamed et al., 2007). The eye tracker must be calibrated for the eyes of each individual participant before it is used.

There are various possible algorithms that can be used to interpret the measurements made by the eye tracker in terms of separating the data out into fixations and saccades – the basic categories of eye movement (Salvucci and Goldberg, 2000). The separate identification of fixations and saccades then allows for a range of various eye movement measures to be collected, such as fixation duration, location, frequency, saccade direction and eye velocity. Careful consideration of the reliability of the algorithm that is to be used is important. For example, the algorithm being too sensitive may identify irrelevant outlying data points and more fixations than the actual number of fixations made, while the algorithm being not sensitive enough may under-represent the number of fixations made. This issue in turn leads to the final result output and the conclusions which are drawn from these to be questionable.

The present study will use a velocity-based algorithm. This involves eye movements that are faster than a set velocity being identified as saccades, and those that are slower than a set velocity, or in other words considered stationary for a set amount of time, being identified as fixations. Salvucci and Goldberg (2000) considered the velocity-based algorithm to be efficient and straightforward. Further details as to how this will be applied to the present experiment can be found in the Method section.

From where the eye is fixated on an area of the text, there are multiple targets towards which the eye could move: the next word, the previous word, previous line, next line, or a jump to somewhere further back or further forward in the text (Engbert et al., 2005). These are all measures that can be analysed using data from an eye tracker. The length, velocity and frequency of fixations and saccades in all directions are able to be measured, as well as the frequency of instances where an eye movement was made twice, in the case of refixations and rereading of the text.

This thesis will explore different eye tracking measures to determine their effectiveness at distinguishing between different reading techniques – specifically comprehension and scanning techniques.

### **Methods of Detecting Differences in Reading Techniques**

Methods other than eye tracking have been used to study reading behaviour. Where these methods are used alongside eye tracking, their results are able to support each other in order to gain a clearer understanding of the eye movements that are being made when reading. This allows for triangulation of the data which increases the strength of the conclusions that can be made about the results.

“EEG [electroencephalography] is a brain-computer interaction technique that monitors brain-wave activities from the human scalp” (Vo and Gedeon, 2011,

p. 397). Vo and Gedeon (2011) proposed that this EEG technology could be used instead of eye tracking technology to measure eye movements when reading, with comparable results. They claim that the movements made by the muscles around the eyes produce waves that can be interpreted by EEG, which tend to be removed from the data by researchers who consider it to be irrelevant noise. However, if the eye movement signals are not removed from the EEG data of reading tasks in reading behaviour research, more information can be learnt about the specific movements of the eyes that were made while reading. Additionally, Vo and Gedeon (2011) suggest that the cognitive processes that take place during reading tasks can also be researched using EEG alongside eye movement research.

Gwizdka, Hosseini, Cole and Wang (2017) carried out EEG testing on participants as they were reading. The readers' task was to answer a question based on the information that could be found in the passage of text, and the EEG results showed activation in different areas of the brain when the participant was reading relevant and non-relevant sections of the text. This response indicated that there was a change in the cognitive processes occurring, at the point where the reader fixated on information that would allow them to answer the given question. Based on the areas of the brain which increased in activity when the eyes moved from non-relevant to relevant text, the researchers could "speculate that brain activity captured by channel FC5 may be related to verbal reasoning; T7 to certain memory functions and auditory processing; T7 and P7 to verbal and reading comprehension, and O2 to visual processing" (Gwizdka et al., 2017, p. 2309). It is therefore evident that looking at text that matches the readers' motivations for reading, and is relevant to their purpose for reading, triggers different cognition processes within various parts of the brain, that are less active when the text is not relevant to the reader's purpose.

Choi and Henderson (2015) used fMRI (functional Magnetic Resonance Imaging) to identify which regions of the brain were activated during reading and picture viewing and whether these differed between the two conditions. Participants read paragraphs and looked at a detailed picture while fMRI technology detected which areas of the brain were activated during these activities. The area of the brain which is referred to as the eye movement control network is located in the frontal and parietal lobes and consists of the frontal eye field, supplementary eye field, and the intraparietal sulcus. These areas of the brain were expected to be activated during both the reading and picture viewing tasks as they are responsible for eye movement, which is required for both of these tasks. As expected, these areas were activated in both of the experimental conditions, as well as some other related regions such as the bilateral visual cortex, which is responsible for visual encoding of stimuli. However, a difference was found in the activation of brain regions between the reading and picture viewing tasks, specifically within the frontal eye field. The reading condition was accompanied by more activation of the lateral frontal eye field and the picture viewing condition was accompanied by more activation of the medial frontal eye field.

Choi and Henderson (2015) explain that the medial frontal eye field may be more responsible for volitional eye movements only, while the lateral frontal eye field is more responsible for reflexive eye movements, although further research is necessary into the specific details about these areas of the brain. This would suggest that one of the primary differences that sets reading apart from scene viewing is the deliberate movement of the eyes. The authors suggest that the eye movements made during reading were more automated than those that were used during picture viewing, meaning that volitional movements were less likely to occur. The results of this fMRI research help to explain the nature of eye movements in reading in that

they may not be deliberately controlled or volitional, which has implications for readers' awareness of the reading techniques that they are using and their ability to modify them at will.

In another fMRI study, Horowitz-Kraus, Grainger, DiFrancesco, Vannest and Holland (2014) used Diffusion Tensor Imaging with fMRI to identify activated areas of the brain when reading, and compared these data to reading comprehension scores in order to determine which areas of the brain are associated with reading comprehension in children. The results focused on the Inferior Longitudinal Fasciculus and the Superior Longitudinal Fasciculus, which are known to be related to language processing. It was found that parts of these areas that are in the right hemisphere of the brain were more strongly activated when the participants who were reading had higher comprehension skills. The researchers therefore concluded that the right hemisphere is primarily responsible for reading comprehension, and further identified that damage to the right hemisphere of the brain can cause reading comprehension problems. This knowledge could aid in differentiating people with reading difficulties such as dyslexia from those who have a lesser ability to comprehend due to damage to the right hemisphere of the brain, particularly the right side of the Inferior and Superior Longitudinal Fasciculus (Horowitz-Kraus et al., 2014).

Self-report components can also be added to the experimental design alongside eye tracking or other methods of studying reading behaviour, as a method of gathering qualitative data to support the eye movement data that is gathered. "Analyzing eye-tracking data in conjunction with debriefing data in the context of the study may facilitate interpretation of the eye-tracking data and can lead to a more comprehensive picture of the participant's behaviour" (Olmsted-Hawala, Wang, Willimack, Stack and Lakhe, 2016, p. 443). The research carried out by

Olmsted-Hawala et al. (2016) involved the use of eye tracking while participants read, with interviews conducted after the reading task. Participants were asked what they had understood from what they had read. This information was then used to support the findings of the eye tracking component which provided information on where on the page the participants had fixated and for how long, as well as which sections of the text had been skipped entirely.

Similarly, Bax (2016) interviewed a sample of students whose eye tracking data had been collected, had them watch a video of their eye movements during a reading task, and asked them about their motivations for making these movements during the task. Participants provided explanations about their reading behaviour, such as fixating for longer on a particular section because they were deciding if it was relevant to the question given, or rereading a piece of text because they hadn't understood it well the first time. The eye tracking data and interview data supply two different sources of evidence of the participant's reading behaviour, strengthening the conclusions that may be made about the results.

### **Reading Techniques: Comprehension and Scanning**

Depending on the given situation, readers may use complex eye movements to create more than one different reading technique to process the text that they are seeing. Reading for comprehension and scanning the text are two reading techniques which are used in different circumstances requiring different outcomes, resulting in different features of eye movement being associated with each technique. The following section discusses the particular eye movements that are associated with the comprehension and scanning techniques of reading, as well as providing the basis of the hypotheses of the present study.

Firstly, before there can be a change in the eye movement patterns that are used, it is necessary for readers to have identified the most useful reading technique to use for the given text type and reading purpose. Early reading research found that readers modify their reading behaviour in response to the type of information that is desired to be gained from the text. Kirsch and Guthrie (1984, p. 336) identified the different situations in which readers may need to use different reading techniques: "... Text search requires an emphasis on specific goal definition, testing text input against goal requirements... In contrast, prose comprehension requires relatively more reliance on processing sentence syntax and comprehending discourse structures (narrative or expository) since these are prevalent characteristics of prose". Here, text search is synonymous with scanning. Although technology has advanced rapidly since this research was undertaken, in more recent research, the appropriateness of the chosen reading technique for the given task is still a relevant consideration. Salmeron, Naumann, García and Fajardo (2016) studied the use of the comprehension (deep-processing) and scanning techniques by students while identifying and reading hyperlinked text within articles on the internet. They noted the decision that had to be made by a student in choosing the appropriate reading technique for the task: "She has to decide which sections of the page and which links to other articles are relevant for her task [scanning information]. Because of the interconnected nature of the Internet, reading the whole collection of linked articles is not a realistic option" (p. 222). In this case, due to the nature of the task, scanning the text for information was more beneficial to the student than reading the text deeply for full comprehension.

When a reader must scan a passage of text for important information, for example when searching for the answer to a question, this involves relevance judgements of each part of the text that they look at, to evaluate whether it warrants

more attention (Gwizdka et al., 2017). Just and Carpenter (1980) claim that readers skip more words when they are scanning or skimming text. It would therefore be expected that the distances between the fixations made, or the 'jump distances', would be larger when scanning the text for particular information compared to reading for comprehension.

A good explanation of the scanning technique is provided by Duggan and Payne (2011), who presented evidence that supported the idea of reading by satisficing. This research explains that readers who are scanning the text have a threshold for information gain when reading, which must be met by each section of the text that they fixate on, in order for attention to be allocated to this section. Once the information had been read and processed, or alternatively if the threshold for relevant information is not met, the reader moves on to the next point of fixation. This account also suggests that readers may make further jumps along the lines of text when they find a lack of text in a particular area that meets their information gain threshold.

Refixations of previously read relevant sections have been shown to result in higher levels of comprehension of the text (Salmeron et al., 2016). In an attempt to achieve this goal, being asked comprehension questions about the text leads to readers making more re-fixations compared to when asked scanning questions, due to comprehension being a more demanding task (Radach, Huestegge and Reilly, 2008). Therefore, it would be assumed that when readers are asked to comprehend the text rather than scan it, they make more left saccades to return to previous areas of the text in order to re-fixate on previously fixated words. Roy and Crabbe (2014) found that the eye movements used by readers when their goal is comprehension of the text, most commonly included re-reading and paying closer attention to what they are reading, which would be expected to manifest in a larger number of

regressive saccades, shorter jump distances, longer fixations and a higher number of fixations when reading for comprehension compared to scanning.

Returning to a previously fixated section of the text after already having processed it indicates more purposeful and higher-order cognitive processes (Jian and Ko, 2017). As the comprehension technique requires deeper and more purposeful processing (Salmeron et al., 2016), it could be expected that reading for comprehension would include more re-fixations.

Salmeron et al. (2016) and dos Santos Lonsdale (2014) both found that students had a tendency to opt to scan the text quickly and not completely read the text, even in sections which were relevant to the question they were being asked. Scanning irrelevant passages of the text may result in lower levels of comprehension of the overall text (Salmeron et al., 2016), however this evidence suggests that some students may not be fully aware of the most beneficial reading technique that they could use to fit their purpose. Roy and Crabbe (2014), conversely, found evidence that students did consider the best reading technique for their given task. There may still be other underlying motivations for the differences between reader decision-making regarding this behaviour.

The reading technique and related eye movement patterns that a reader uses can be triggered without the reader being explicitly asked to use certain techniques. In research carried out by Radach et al. (2008), participants were instructed to read the text for comprehension in all conditions, but it was expected that the type of question that participants were asked about the text after each trial – either comprehension questions or short multiple choice questions – would inform their choice of either comprehension techniques or scanning techniques for the subsequent trials: “No further explanations were given so that readers were led to accommodate the present reading situation on the basis of the type of questions and

formats they encountered during the following training trials.” (p. 681). Another method of triggering the desired reading technique was used by Salmeron et al. (2016): Participants were asked a question which required an answer that integrated information from various sections of the text, requiring the reader to have read and understood the entire text. This encouraged reading for comprehension rather than scanning or skimming.

### **Factors Affecting Reading Behaviour**

There are many considerations to be made about the factors that affect the eye movements that are made by the reader. These may be factors that differ within the text that is being read, or factors that differ between individual readers. When carrying out reading research, it should be taken in to account that eye movements may vary when affected by these factors.

Text is extremely versatile and can be presented in many different ways to the reader. Font size, style and spacing can vary greatly. The types of words used – in relation to their familiarity to the reader, frequency of use within the language, and length – can also vary greatly (Juhasz and Rayner, 2003). These factors can have an effect on the reader’s ability to process the information in the text, and the methods that they use to do so.

Enkin, Nicol, Brooks and Zavaleta (2017) demonstrated the Frequency Effect with the inclusion of lower frequency words in a passage of text resulting in longer fixation durations, longer total time spent in an area of interest, and a higher number of fixations. Higher frequency words were also recognised more quickly by readers than lower frequency words were.

Juhasz and Rayner (2003) found that all measures of fixation duration are affected by both word frequency and level of familiarity of words that are used

within the text, and note that these variables are important to be aware of when carrying out reading research, as they account for some of the variability of eye movements when not kept constant. Similarly, the predictability of words within text can have an effect on the eye movements made when reading (Luke and Christianson, 2017). Readers make more fixations when the text they are reading has fewer familiar words (Just and Carpenter, 1980).

Korneev, Matveeva and Akhutina (2017) found that eight-year-olds who were reading a Russian text, which was their native language, made an increasingly higher number of fixations and fixated for an increasingly longer time as words increased in length, which demonstrates the effect that the length of the words within a text can have on reading behaviour. Juhasz and Rayner (2003) also found that longer word length predicted longer fixation durations, total fixation duration and the number of refixations.

According to Radach et al. (2008, p. 685), "...it appears that there is a marked difference in how readers approach the tasks of reading when confronted with single sentences versus passages as part of integrated nonfictional text". This study compared the reading of passages with the reading of single line sentences and noted significantly longer word viewing time for passages, despite shorter first-pass viewing times for passages. This suggests that readers are more likely to re-read a passage than a single line sentence and indicates that reader behaviour differs depending on the presentation of the text that is being read.

Dos Santos Lonsdale (2014) reported that legibility is the most important factor for reading performance. This research found that more widely spaced out text allowed for better legibility, which resulted in readers being able to find important information in the text more efficiently and accurately.

These studies highlight the importance of taking into account the different factors that may affect the eye movements during reading when designing a reading experiment. Where the behaviour of the reader is the variable of interest in the experiment, careful consideration of word length, word difficulty, word frequency and familiarity, and the visual presentation of text will help to maintain the validity of the reading experiment and reduce the possibility of the results being affected by differences within the text.

The eye movements made during reading can also be affected by personal factors such as the engagement and mind wandering habits of the reader, as well as metacognitive strategies that are being consciously used by the reader.

The level of a reader's engagement in the text can vary throughout the task of reading, and the eye movements that are made can reflect this engagement. As level of engagement is identified by the amount of cognitive resources that a person allocates to their task, especially the level of attention, students who are highly engaged in their reading will have allocated a large ratio of their cognitive resources towards the processing of the text (Miller, 2015).

In contrast to this, mind wandering is also a frequently occurring phenomenon during reading tasks. Dixon and Li (2013, p. 1) identified mind wandering as "the allocation of resources to mental processes unrelated to the current task". According to their research, mind wandering is not a deliberate or conscious decision, and the cognitive resources that are allocated to it are not controlled by the reader. McVay and Kane (2012) found that mind wandering is related to the individual's working memory capacity. They claim that readers who have a higher working memory capacity are more likely to be able to control the allocation of their attention, allowing them to stay focused on their task and better comprehend what they are reading.

According to Jian and Ko (2017), the degree of cognitive effort required to process what is being read and the difficulty of the reading task can be measured by the total reading time. Similarly, mean fixation duration indicates the length of processing time required by the reader, while the number of fixations indicates how much attention and cognitive investment are employed by the reader when undertaking the reading task. Henderson and Luke (2014) also claim that perceptual and cognitive processing difficulty are variables that affect fixation duration and saccade amplitude, meaning the distance of the jump from one fixation point to the next.

The level of engagement that the reader has in the text, the amount of mind wandering that takes place, and the degree of cognitive effort, as variables that influence the process of reading, may therefore influence the eye movements that are made when reading. Taking this into consideration when carrying out reading research may help to form a better understanding of the underlying causes of the possible differences between the eye movements made in different situations.

Metacognitive strategies involve the reader being conscious of the way that they are undertaking the reading task and making a conscious effort to optimise this. Metacognitive strategies can be used by readers to evaluate their understanding of what techniques they are using to read, which may include comprehension or scanning strategies. The use of metacognitive strategies by the reader may also have an impact on the eye movements that are made.

Roy and Crabbe (2014) used a variety of questionnaires to determine how Japanese learners of English as a foreign language used reading techniques to comprehend information on an English website. It was determined that the participants had a high awareness of the strategies they were using when reading, including: 'I have a purpose in mind when I read', 'I think about whether the content

of the text fits my reading purpose’, ‘I adjust my reading speed’, ‘I pay close attention to what I am reading’ and ‘I re-read text when comprehension becomes difficult’.

Liu (2014) studied the effect of a concept-mapping technique taught to students who were learning English as a foreign language. It was expected that concept mapping would improve the reader’s comprehension of the text. As part of the concept mapping training, participants were taught to scan the text for relevant information which was then organised into a drawn diagram showing the concepts that were presented in the text. Students then used the concept map as a resource when answering comprehension questions about the text. The participants’ eye movements were tracked as they read. Liu (2014) found that participants who had been taught the concept-mapping technique made fewer regressions (define) when reading, shorter rereading time and larger jump distances than the control group. It was suggested that the control group were less able to identify the relevant information in the text, which had been achieved by the concept-mapping group through scanning the text, jumping to the relevant sections and not spending equal amounts of time on all sections of the text. This research is an example of English learners being successfully taught a reading technique which involves moving their eyes around the page in a specific way – in this case scanning by skipping less relevant sections and allocating their attention to relevant sections. People who are seeking to improve their reading abilities may benefit from being taught a technique such as concept mapping, along with instructions and guidance regarding the eye movements required for scanning the text efficiently.

## **Comparison with Existing Research**

There is a lack of research measuring and comparing the differences between the eye movements that are used in combination to make the comprehension and scanning techniques possible, as they are used by the same individual on a full page of text. The present study aims to contribute towards better understanding in this area of eye movement research. Previous research that has examined the different eye movements made under scanning or comprehension conditions has often been limited to the analysis of single sentences, languages other than English, and the reading behaviour of children or non-native English speakers. Evidence of the eye movements that are made when using different reading techniques by fully developed, native English-speaking adults with normal reading patterns is therefore relatively scarce.

White, Warrington, McGowan and Paterson (2015) compared comprehension and scanning techniques while reading and found that participants who were reading for comprehension had longer total first-pass reading time, longer rereading time, longer average fixation durations and a higher number of fixations than those who were scanning. Readers who were scanning the text had longer saccade forward jump distances than those who were reading for comprehension.

The present study is generally expected to produce a similar pattern of results. First-pass reading time may be equated with total fixation time as a measure for the purposes of the present research, based on the principle that almost no processing takes place during saccades, making saccade time less relevant (Salvucci and Goldberg, 2000), and considering that total reading time would not represent first-pass reading time as this measure may include time spent rereading. Total fixation time therefore would be expected to align with first-pass reading time results.

However, the participants in the research carried out by White et al. (2015) were reading single sentences at a time. As comprehension and scanning techniques are most likely to be used as part of studying, learning or working reading behaviour, it is most appropriate that the current research focuses on eye movement changes while reading longer passages of text rather than single sentences, where the reading behaviour may begin and end before the participant has had sufficient time to employ a reading technique such as scanning or reading for comprehension. A full page of text will simulate a more natural, everyday reading scenario and possibly result in more reliable and transferable eye movement measurements.

It should be noted that although the present research focuses on reading in the English language, some eye tracking research which contributes towards the literature in terms of the expected eye movements when reading has been conducted in other languages. Research discussed within this thesis includes Korneev et al. (2017) in which the participants were reading in Russian, Murata, Miyamoto, Togano and Fukuchi (2017) in which the participants were reading in Japanese, Kriber, Bartl-Pokorny, Pokorny, Einspieler, Langmann, Körner, and Marschik, (2016) and Kliegl et al. (2006), both of which were conducted in German, and Enkin et al. (2017) in which participants were native speakers of English reading in Spanish as a second language. Clearly demonstrating this issue, Kliegl et al (2006) mentioned that there were seven words in the text used that were 14 to 20 letters long. This is common in German but would be very uncommon in English, and would result in there being differences in factors such as the average number of words per line and the number of fixations made per word. The language differences in the literature should be taken into account when drawing comparisons between study results.

## **Applications**

Research into the specific eye movements that are made during the process of reading may uncover further tools that can be used for reading teaching and training. A better understanding of reading eye movements could benefit various groups of people.

Generally, children who are being taught to read are not made aware of the eye movements that they are using or the movements that may be the most effective, although this knowledge may be useful for developing the skill and technique of reading. Those who wish to improve their reading technique for the motivations of work or study may also benefit from training modifying their eye movements to best suit their required reading purposes.

Some students who are learning English as a second language may have learnt to read using different eye movements from what is standard for reading English, for example those who first learnt to read Arabic, which is read right to left; Thai, which has no spaces between words; or Chinese, which uses logographic orthography. In these cases, although the technique of reading has already been learnt, the reader may benefit from instruction in the different eye movements that are involved in reading English – something which is likely otherwise overlooked by English learners.

Some people who have abnormal reading behaviour may also seek to change the reading techniques that they use, where the knowledge of the different eye movements that can be used to read may be useful. “Dyslexic readers are generally agreed to have reading and spelling problems, difficulty learning rhymes, and often omit and reverse the orientation of letters when writing. They are also generally slower to read and write.” (Jones, Obregon, Kelly and Branigan, 2008, p. 389).

People who have reading difficulties may exhibit these difficulties through different eye movements compared to those that the general majority of the population make while reading (Jones et al., 2008). People with reading difficulties such as dyslexia may make different eye movements to those that are considered normal or standard. In addition to helping towards modifying the eye movements that are made by individuals who have reading difficulties, a clear understanding of the normal eye movements that are made while reading may be used to identify abnormal eye movements and help with the diagnosis of reading difficulties.

Nilsson Benfatto, Öqvist Seimyr, Ygge, Pansell, Rydberg and Jacobsen (2016) used a machine learning algorithm to create a classification system to identify eye tracking data as belonging to either a high risk or low risk reader. This programme could be used to screen for readers with dyslexia, which affects an estimated 5-10% of the population. The programme was able to identify the eye movements of interest for a reader with dyslexia as progressive fixations, progressive saccades, regressive fixations and regressive saccades, in about equal amounts. It was however unclear how these eye movement measurements were different for low-risk readers and high-risk readers, as decided by the algorithm. According to Rayner (2006), low-skilled readers and dyslexic readers show longer fixations, shorter saccades, and more backward regressions when reading compared to average readers of the same age.

Kapoula (2012), also found that in comparing the eye movements of dyslexic children and non-dyslexic children, saccade velocities were on average the same, however, children with dyslexia had longer saccade latencies, which meant taking longer to begin a saccade to a new stimulus once it had appeared. This may in part explain why other studies have found that longer fixation durations are related to dyslexia, particularly following the Just and Carpenter (1980) theory of reading.

Dyslexic readers may be fixating on words for longer because of a longer amount of time being necessary to process each word, or, as Kapoula (2012) states, longer fixation durations may be occurring because of saccade latency, where there is a delay in movement to the next word. Longer fixation durations, then, would not necessarily be caused by the word processing time being longer. It is also possible that longer word processing time and saccade latency are both issues that are present in the case of dyslexia, meaning that the Just and Carpenter theory (1980) and Kapoula's (2012) evidence, are not mutually exclusive by any means. More research is still needed in order to clarify the complex relationship between eye movements and word processing for readers with dyslexia.

Knilians and Dede (2015) found that people with aphasia appeared to use different reading strategies for comprehension than a control reading group, as people with aphasia were more likely to spend longer on the second pass through the text and also longer to read overall. This suggested that the cognitive processing of what is read may be achieved differently by people with aphasia, which is manifested in their recorded eye movements.

In a study which compared the reading behaviours of participants who had Autism Spectrum Disorder with those who had typical development, Howard, Liversedge and Benson (2017) found that those readers with Autism Spectrum Disorder spent longer re-reading sentences, made more fixations, and skipped fewer words. The authors suggested that these measurements may have been a result of those with Autism Spectrum Disorder tending to use more cautious reading strategies. Word Frequency Effects were observed as affecting both groups equally, and the number of regressions made by both groups was also the same on average.

Eye movements may be used to identify issues that people are having while reading, due to a wider medical issue. Henderson and Luke (2014) claim that

differences in eye movements may be used to help measure cognitive processes in cases such as brain damage or stroke. With specific attention to diseases of the eyes, Murata et al. (2017) found a difference in eye movement patterns between glaucoma and readers with normal sight, including longer fixation durations.

Knowledge of eye movement patterns may also be useful in other sectors such as marketing, where advertisers and designers seek to understand the perception of the written content that is aimed at consumers. For example, regarding the display of written information on web pages, it has been found that readers are likely to skip large sections of text if they do not find information that catches their attention at the beginning of the page (Duggan and Payne, 2011). Knowledge of reading eye movements could be used to organise the text in a way that would encourage readers to spend longer looking at it. The scanning behaviour of readers of web pages is valuable information for businesses who market to consumers online (Campbell, 2005). It is therefore in the best interest of advertisers, and others who publish written information, to take the eye movements of their readers into account when designing the layout of their web pages.

### **The Present Study**

The primary research question of this thesis is: How are the eye movements of readers different when reading for comprehension compared to scanning the text for information? The research also aims to identify whether it is possible to successfully determine the difference between comprehension and scanning reading techniques based on the eye movements that are used for each technique. Kaakinen et al. (2018) argued that eye movement measures such as fixation durations do not provide a quality understanding of the cognitive processes during reading. This claim highlights the need for research into which eye movement

measures, or which combinations of these measures, are powerful enough to build a clear understanding of the differences in the underlying cognitive processes that take place while readers are either reading for comprehension or scanning the text.

The present study also includes features designed to overcome some of the limitations of previous studies that have measured differences between reading techniques. Eye movement measurements should be collected for a section of text that occurs in the context of several pages of text, allowing the reading behaviour in the experiment to closely reflect that which would occur under 'natural' conditions, such as while studying. Care should also be taken to closely match the properties of the sections of text used to compare the two reading methods.

### **Hypotheses**

Based on the existing research on the differences between comprehension and scanning techniques, the hypotheses of the present experiment are that:

1. Fixation duration will be higher when reading for comprehension.
2. Total fixation time will be higher when reading for comprehension.
3. Number of fixations will be higher when reading for comprehension.
4. Number of backwards saccades (regressions on the same line) will be higher when reading for comprehension.
5. Total reading time will be higher when reading for comprehension.
6. Number of rereads (fixations on previous line) will be higher when reading for comprehension.
7. Jump distance will be higher when scanning the text.

# **Method Section**

## **Participants**

The experiment involved 16 participants, with a mean age of 21 years and ranging from 18-43 years. 11 participants were female (68.75%), 4 participants were male (25%) and one participant was gender diverse (6.25%). Participants were required to have normal vision in order to use the eye tracker – therefore participants who used glasses or thick contact lenses for reading were excluded. Participants were also required to be fluent in the English language. All participants had English as a native language. Participants were recruited from a first-year psychology undergraduate course and received course credit for their participation. Each participant read an information sheet and signed a consent form (see Appendices A and B). This research was approved by the Human Research Ethics committee at the University of Waikato.

## **Apparatus**

The stimuli were displayed on a screen with 1920 pixels in width and 1200 pixels in height. The screen had a horizontal field of view of 40.9 degrees and a vertical field of view of 25.6 degrees.

An Eyelink 1000 desk-mounted eye tracker recorded the participants' eye movements. A head rest for the participants was positioned at 65cm distance from the screen in order to minimise head movement. Participants used a keyboard to interact with the stimuli, which were operated using Experiment Builder software (SR Research Ltd, Ontario, Canada). Only the movements of the right eye were recorded.

## **Materials**

### Reading Stimuli

The stimuli used were a page of text extracted from a book (Maunder, 1913, pp. 1-19, see Appendix C) preceded by questions about the text (see within Appendix D) which were used to trigger either the comprehension or scanning techniques used to read the piece of text. *Figure 1* shows the presentation of the first page of the text from Chapter One, with a question about the text at the top of the page. *Figure 2* shows the presentation of the first page of the text from Chapter Two, with a question about the text at the top of the page. The question about the text was only present on the pages in the Scanning condition. There was blank space in this area on all pages in the Comprehension condition.

### Questionnaire

The questionnaire sheet included questions about the participants' reading habits as well as demographic questions (see Appendix E). There were seven questions which required the participant to either provide a short answer or a rating. There was also a space provided for participants to write other comments if they wished to do so. The questionnaire was provided to participants in paper form. A separate sheet of paper was provided after the completion of the reading tasks on which participants answered the comprehension and scanning questions related to the text.

Please scan the whole text to find the answer to this question:

In what year did Dr. A. R. Wallace revive the discussion on the theological concepts of other worlds?

## CHAPTER I

### THE QUESTION STATED

THE first thought that men had concerning the heavenly bodies was an obvious one: they were lights. There was a greater light to rule the day; a lesser light to rule the night; and there were the stars also.

In those days there seemed an immense difference between the earth upon which men stood, and the bright objects that shone down upon it from the heavens above. The earth seemed to be vast, dark, and motionless; the celestial lights seemed to be small, and moved, and shone. The earth was then regarded as the fixed centre of the universe, but the Copernican theory has since deprived it of this pride of place. Yet from another point of view the new conception of its position involves a promotion, since the earth itself is now regarded as a heavenly body of the same order as some of those which shine down upon us. It is amongst them, and it too moves and shines—shines, as some of them do, by reflecting the light of the sun. Could we transport ourselves to a neighbouring world, the earth would seem a star, not distinguishable in kind from the rest.

But as men realized this, they began to ask: "Since this world from a distant standpoint must appear as a star, would not a star, if we could get near enough to it, show itself also as a world? This world teems with life; above all, it is the home of human life. Men and women, gifted with feeling, intelligence, and character, look upward from its surface and watch the shining members of the heavenly host. Are none of these the home of beings gifted with like powers, who watch in their turn the movements of that shining point which is our world?"

This is the meaning of the controversy on the Plurality of Worlds which excited so much interest some sixty years ago, and has been with us more or less ever since. It is the desire to recognize the presence in the orbs around us of beings like ourselves, possessed of personality and intelligence, lodged in an organic body.

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This is what is meant when we speak of a world being "inhabited." It would not, for example, at all content us if we could ascertain that Jupiter was covered by a shoreless ocean, rich in every variety of fish; or that the hard rocks of the Moon were delicately veiled by lichens. Just as no richness of vegetation and no fulness and complexity of animal life would justify an explorer in describing some land that he had discovered as being "inhabited" if no men were there, so we cannot rightly speak of any other world as being "inhabited" if it is not the home of intelligent life. If the life did not rise above the level of algæ or oysters, the globe on which they flourish would be uninhabited in our estimation, and its chief interest would lie in the possibility that in the course of ages life might change its forms and develop hereafter into manifestations with which we could claim a nearer kinship.

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On the other hand, of necessity we are precluded from extending our enquiry to the case of disembodied intelligences, if such be conceived possible. All created existences must be conditioned, but if we have no knowledge of what those conditions may be, or means for attaining such knowledge, we cannot discuss them. Nothing can be affirmed, nothing denied, concerning the possibility of intelligences existing on the Moon or even in the Sun if we are unable to ascertain under what limitations those particular intelligences subsist.

*Figure 1.* Page 1, Chapter 1 of the text presented to participants in the Scanning condition.

Two horizontal lines either side of the penultimate paragraph indicate the section of the text that was used for analysis.

Please scan the whole text to find the answer to this question  
How is metabolism described?

## CHAPTER II THE LIVING ORGANISM

A WORLD for habitation, then, is a world whereon living organisms can exist that are comparable in intelligence with men. But "men" presuppose the existence of living organisms of inferior grades. Therefore a world for habitation must first of all be one upon which it is possible for living organisms, as such, to exist.

It does not concern us in the present connection how life first came into existence on this planet. It is sufficient that we know from experience that life does exist here; and in whatsoever way it was first generated here, in that same way we may consider that it could have been generated on another planet.

Nor need any question trouble us as to the precise line of demarkation to be drawn between inorganic and organic substances, or amongst the latter, between plants and animals. These are important subjects for discussion, but they do not affect us here, for we are essentially concerned with the highest form of organism, the one furthest from these two dividing lines.

It suffices that living organisms do exist here, and exist under well-defined conditions. Wanting these conditions, they perish. We can, to a varying degree, determine the physical conditions prevailing upon the heavenly bodies, and we can ascertain whether these physical conditions would be favourable, unfavourable, or fatal to the living organism.

What is a living organism? A living organism is such that, though it is continually changing its substance, its identity, as a whole, remains essentially the same. This definition is incomplete, but it gives us a first essential approximation, it indicates the continuance of the whole, with the unceasing change of the details. Were this definition complete, a river would furnish us with a perfect example of a living organism, because, while the river remains, the individual drops of water are continually changing. There is then something more in the living organism than the continuity of the whole, with the change of the details.

An analogy, given by Max Verworn, carries us a step further. He likens life to a flame, and takes a gas flame with its butterfly shape as a particularly appropriate illustration. Here the shape of the flame remains constant, even in its details. Immediately above the burner, at the base of the flame, there is a completely dark space; surrounding this, a bluish zone that is faintly luminous; and beyond this again, the broad spread of the two wings that are brightly luminous. The flame, like the river, preserves its identity of form, while its constituent details—the gases that feed it—are in continual change. But there is not only a change of material in the flame; there is a change of condition. Everywhere the gas from the burner is entering into energetic combination with the oxygen of the air, with evolution of light and heat. There is change in the constituent particles as well as change of the constituent particles; there is more than the mere flux of material through the form; there is change of the material, and in the process of that change energy is developed.

A steam-engine may afford us a third illustration. Here fresh material is continually being introduced into the engine there to suffer change. Part is supplied as fuel to the fire there to maintain the temperature of the engine; so far the illustration is analogous to that of the gas flame.

*Figure 2.* Page 1, Chapter 2 of the text presented to participants in the Scanning condition.

Two horizontal lines within the penultimate paragraph indicate the section of the text that was used for analysis.

## **Procedure**

The experiment took place in a laboratory with normal room lighting. Participants were seated in front of the screen and the eye tracker was calibrated for each individual participant before instructions were presented on the screen (see Appendix D) the experiment began. There were two conditions: reading for comprehension (Comprehension) and scanning for particular information (Scanning). The Comprehension condition involved the participant reading the text and then being asked to summarise the main idea of the text. Participants were instructed beforehand to read the text carefully and make sure that they understood it, and made aware that they would be asked a question about the text after reading. The Scanning condition involved the participant first being presented with one question to which they were to find answers in the following text. The questions that participants were instructed to find the answer to were presented before the participant was presented with the text but were also available above the reading material at the top of the screen, as seen in *Figure 1*, so that participants were not required to memorise the questions. Participants were not instructed to read carefully or make sure that they understood the text for the Scanning condition. Participants wrote the answers to the questions on a piece of paper provided at the end of each trial. Each chapter had two pages of text and participants moved to the second page by pressing the Enter key on the keyboard. In the case of the Scanning condition, the answers to the questions were always found on the second page of the text. After completing both conditions, participants filled in the questionnaire sheet.

## **Experiment Design**

The experiment had a repeated-measure within-subjects design to allow comparisons to be made between the comprehension and scanning reading

movements that were used by the same individual participant. Participants were required to read different pages of text for each condition, to avoid the participant having to read the same text twice and becoming familiar with the text during their second reading task, which could affect their reading behaviour. Each participant completed both the Comprehension and Scanning conditions, with the order that the participants were assigned the conditions being counterbalanced, to reduce fatigue effects. Those participants who were randomly assigned Chapter One for the Comprehension condition were assigned Chapter Two for the Scanning condition, and vice versa. Both Chapter One and Chapter Two of the same book were used, as the chapters were written in the same style and therefore considered to be comparable.

### **Data Analysis**

Lines drawn above and below the penultimate paragraph on the page can be seen in *Figure 1*, which depicts the section that was selected for eye movement analysis. These sections were considered to be suitable for comparison – being similar in average number of words per line, average number of letters per line, average number of letters per word, position within the page of text (being the penultimate paragraph on each page) and visual space occupied.

It was necessary that the sections of text chosen for analysis from Chapter One and Chapter Two of the reading material were not significantly different, so that the eye movements of each participant in both reading conditions could be compared regardless of which chapter the participant had been reading. Independent samples t-tests were conducted to ascertain that the Chapter One section and Chapter Two section of the reading material were not significantly different in the measures listed above. There was no significant difference in the

average number of words per line for the Chapter One ( $M = 20.75$ ,  $SD = 3.15$ ) and Chapter Two ( $M = 20.5$ ,  $SD = 1.69$ ) sections;  $t(14) = 0.198$ ,  $p = 0.8461$ . There was no significant difference in the average number of letters per line for the Chapter One ( $M = 91.50$ ,  $SD = 6.72$ ) and Chapter Two ( $M = 95.88$ ,  $SD = 6.08$ ) sections;  $t(14) = 1.366$ ,  $p = 0.194$ . There was no significant difference in the average number of letters per word for the Chapter One ( $M = 4.48$ ,  $SD = 0.54$ ) and Chapter Two ( $M = 4.72$ ,  $SD = 0.62$ ) sections;  $t(14) = 0.820$ ,  $p = 0.426$ .

Using the SUBTLEXus word frequency classification software created by Brysbaert and New (2009), it was determined that the words used in the selected section from Chapter One and Chapter Two ranked at a similar level for their frequency of use in the English language. An independent samples t-test showed that there was no significant difference between the average word frequencies in the English language for the Chapter One ( $M = 2561.23$ ,  $SD = 4832.39$ ) and Chapter Two ( $M = 2387.18$ ,  $SD = 5322.02$ ) sections;  $t(14) = 0.241$ ,  $p = 0.810$ . This result indicates that the both sections contained words which were about equally as commonly used in the English language, meaning that one section should not have been more difficult to read or unfamiliar than the other.

The Eyelink data produced by the eye tracker were converted into a readable file (.asc). Data from the experiment was analysed using custom code written in Matlab (Version R2017a); Mathworks.

The X and Y position versus times traces were smoothed using a 2-D Gaussian filter (standard deviation = 5 milliseconds). *Figure 3* shows the smoothed data for the x position (horizontal) of the eyes across the screen from left to right over time, and *Figure 4* shows the smoothed data for the y position (vertical) of the eyes from the top to the bottom of the screen over time.

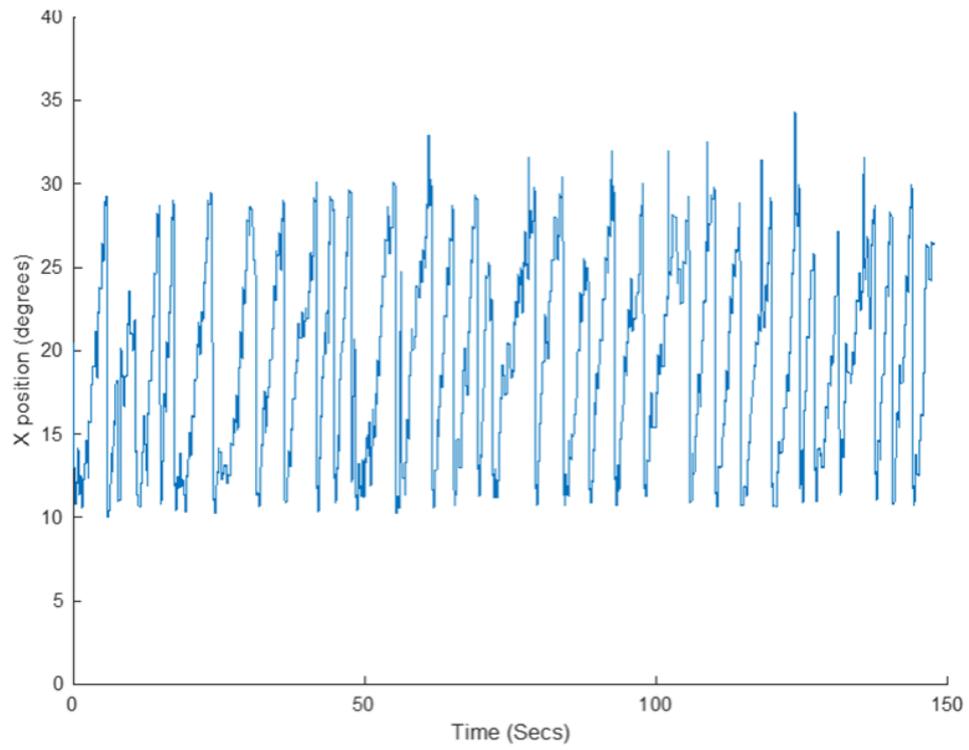


Figure 3. Smoothed X position of the eyes (in degrees) across the screen over time (in seconds).

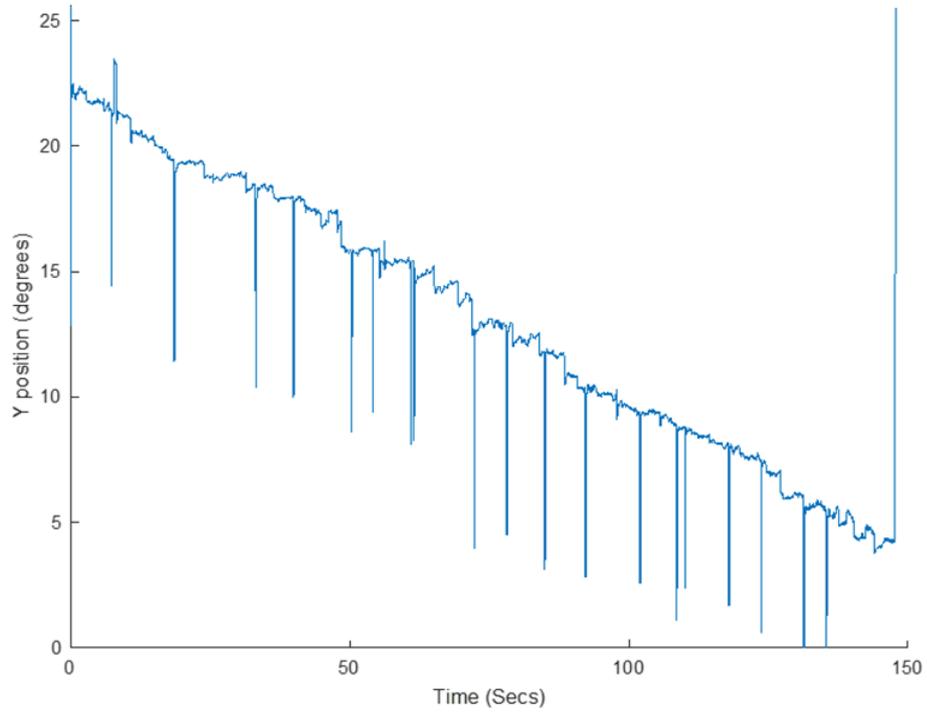
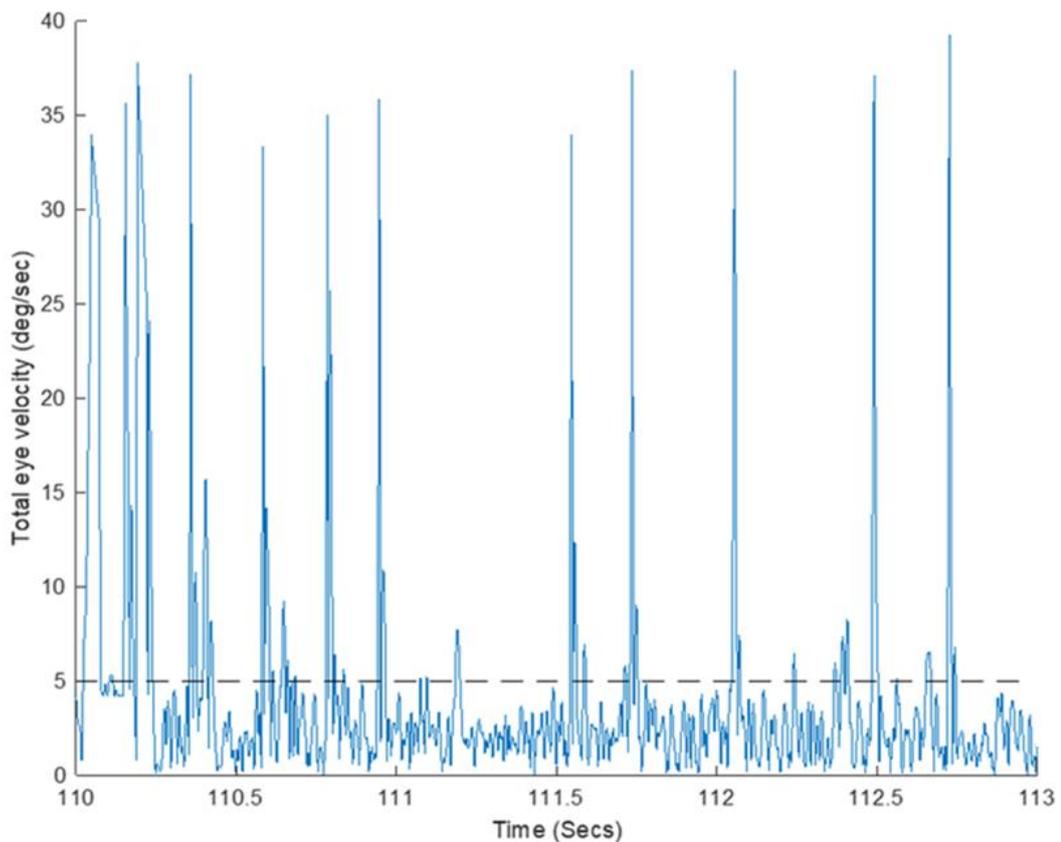


Figure 4. Smoothed Y position of the eyes (in degrees) across the screen over time (in seconds).

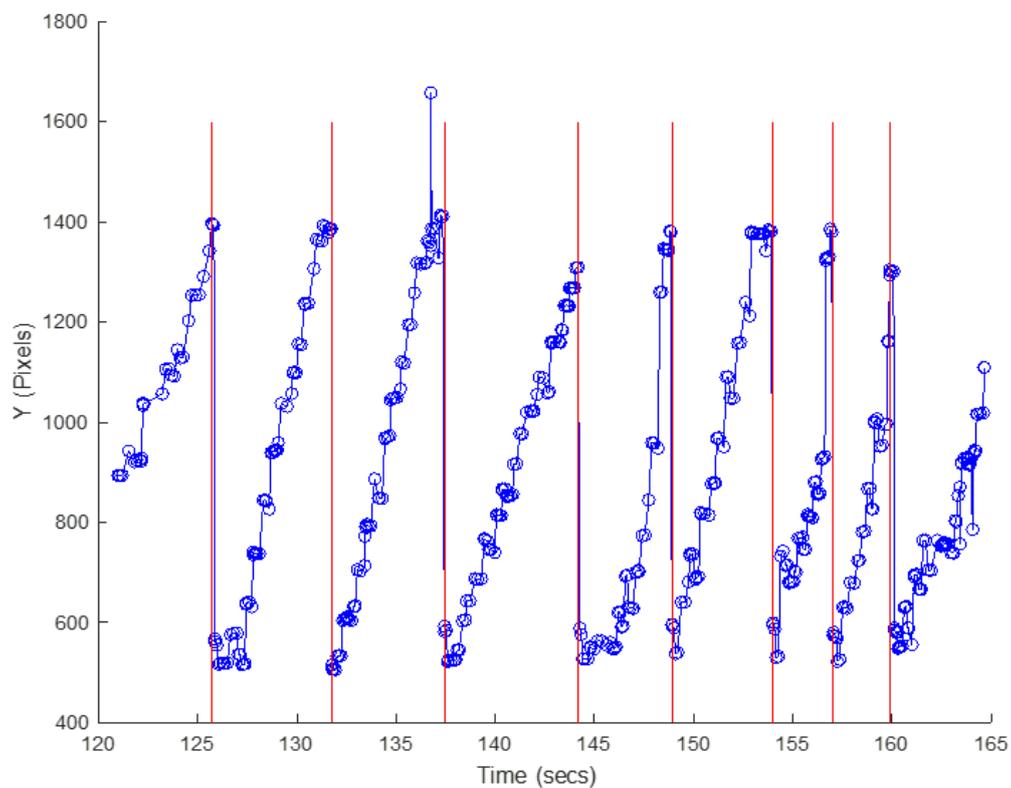
Velocity was derived using change of positions over time  $((P2-P1)/(T2-T1))$ , where P equals the different positions in pixels and T equals the timestamp of those positions (milliseconds). The total eye velocity was found from  $\sqrt{Xvel^2 + yvel^2}$ . This velocity (in pixels per millisecond) was converted to degrees per second using a pixel to degree conversion factor = 0.0213. This is the unit for velocity reported throughout the thesis.

Fixations were estimated as locations in the velocity trace where V dropped below 5 deg/s, as seen in *Figure 5*. The fixation time (in msec) was the time between the velocity dropping below 5 deg/s and then rising back above 5 deg/s. The location of the fixation was the mean location between these two endpoints.



*Figure 5.* Total eye velocity (in degrees per second) across time (in seconds) with a line at 5 deg/sec dividing the fixations below the line and saccades above the line.

The lines of the paragraph of text were separated using the locations of the sudden drops in fixation Y values, as these were the locations where the participant's eyes dropped down to read the next line (see *Figure 6*). Only the first five lines of the section were included in the analysis for fixation length and velocity, as a simplified representative sample of the eye movements that occurred within the section. This was due to the observation that in the Scanning condition, rereading began to occur after the participant had read the first five lines of the paragraph, adding more noise to the data.

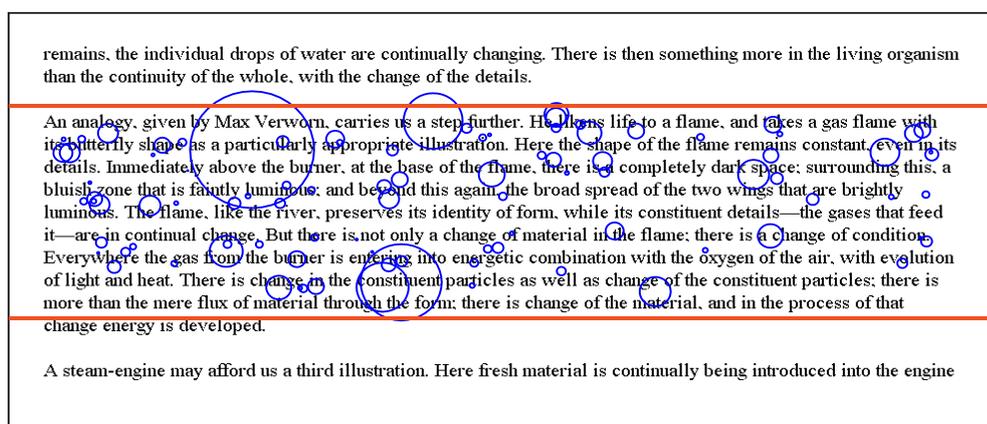


*Figure 6:* The Y positions of fixations made across time (in seconds), with red lines depicting the locations of the sudden drops that indicated a new line.

Fixations which were shorter than 10ms were removed from the data, due to the fact that these extremely short fixation measurements are not clearly long enough to be classified as fixations where the participant was able to process

information about the point that they were looking at, and the very high frequency of them skewed the data towards much smaller averages of fixation times which would misrepresent the nature of the reading eye movement data.

*Figure 7* shows the locations of the fixations made by an individual reader on the section of text that was used in the experiment. Each fixation is represented by a circle. The circle size for each fixation is proportional to the length of the fixation. Every fifth fixation is shown, for clarity.



*Figure 7:* A visualisation of the locations of fixations made by an individual reader on a section of text used in the experiment. Every fifth fixation is shown. Circle size for each fixation is proportional to the length of the fixation.

### Statistical Tests

Paired samples t-tests were conducted to determine whether there was a significant difference between the Comprehension and Scanning for each eye movement measure.

Additionally, correlation tests – and where necessary Analysis of Covariance tests – were carried out to determine possible personal factors that may have influenced the main eye movement measure results.

## Eye Movement Measures

The smoothed data was used to provide the measures which were the dependent variables in the experiment, to be compared between the two reading conditions. These measures and their definitions are as follows:

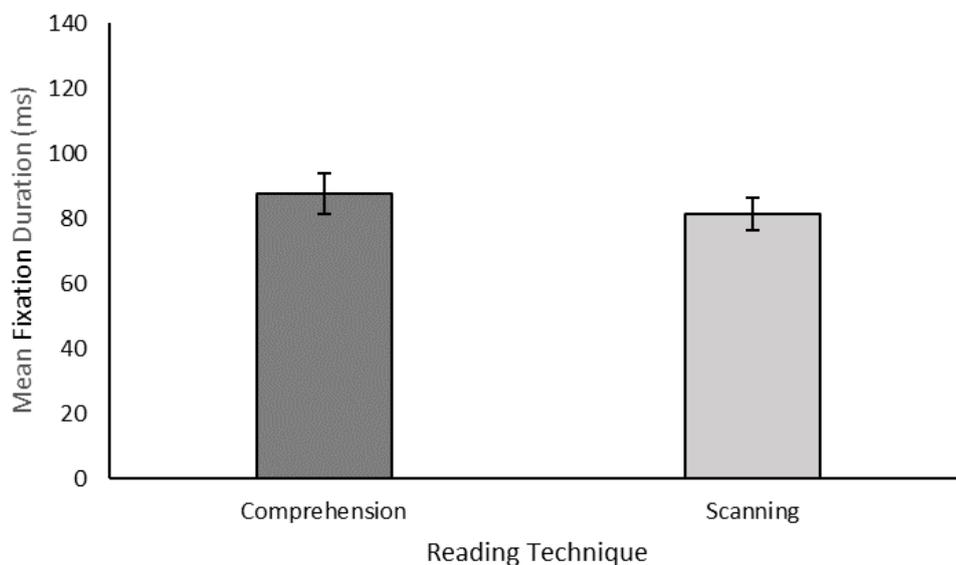
- Fixation duration: the length of time taken by the eyes fixed without movement on one location, measured in milliseconds.
- Total fixation duration: the total sum of time taken by the eyes fixed without movement, measured in seconds.
- Number of fixations: the number of instances of the eyes being fixed without movement on one location.
- Forward jump distance: the distance from one fixation to the next, moving from left to right, measured in degrees.
- Number of backward jumps: the number of instances of a fixation occurring to the left of the previous fixation point, on the same line of text. This indicates that a participant is re-reading a small part of the text that they have already read or skipped over.
- Number of previous line jumps: the number of instances of a fixation occurring on a line of text that is above the previous fixation point. This indicates that a participant is re-reading a larger part of the text that they have already read or skipped over.
- Length of total reading time: length of time taken from when the participant starts reading the section until they have finished reading the section, including any re-reading that took place.

# Results

## Fixation Duration

The mean fixation duration was a measure of the length of time taken on average by the eyes fixed without movement on one location, measured in milliseconds. This was calculated across the first five lines of text from each section that was selected for analysis.

Paired samples t-test results showed that there was no significant difference in mean fixation duration for the comprehension ( $M = 87.66$ ,  $SD = 25.00$ ) and scanning ( $M = 81.15$ ,  $SD = 20.23$ ) conditions;  $t(15) = 1.446$ ,  $p = .169$ , Cohen's  $d = .286$ . Therefore, the fixations that participants made lasted on average about the same amount of time regardless of whether the participant was reading for comprehension or scanning the text (see *Figure 8*).

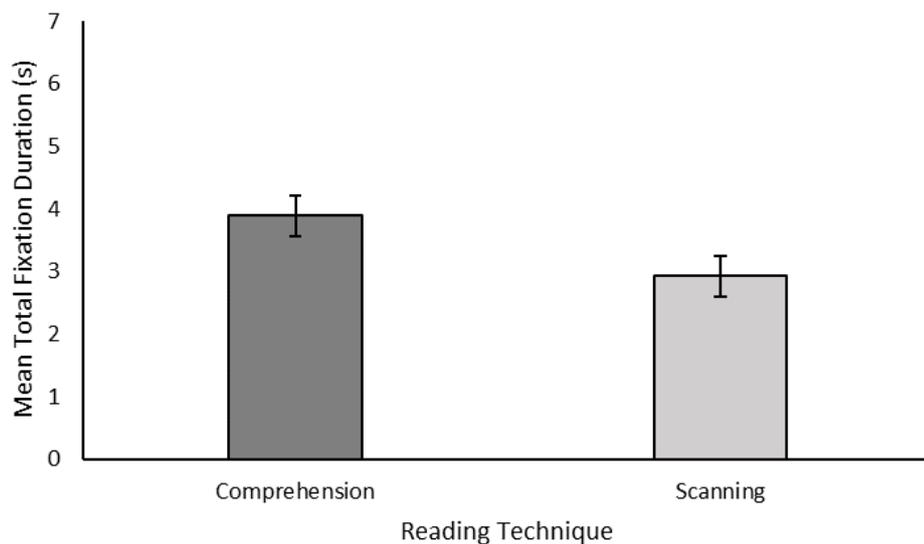


*Figure 8.* Mean duration of fixations (in milliseconds) for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Total Fixation Duration

The mean total fixation duration was a measure of the total sum of time on average taken by the eyes fixed without movement, measured in seconds. This was calculated across the first five lines of text from each section that was selected for analysis.

Paired samples t-test results showed that there was a significant difference in mean total fixation duration for the comprehension ( $M = 3.89$ ,  $SD = 1.29$ ) and scanning ( $M = 2.93$ ,  $SD = 1.32$ ) conditions;  $t(15) = 3.041$ ,  $p = .008$ , Cohen's  $d = .736$ . Therefore, when all fixation duration times are added together, the mean total time spent fixating while reading the text was longer when the participant was reading for comprehension compared to when scanning the text (see *Figure 9*).

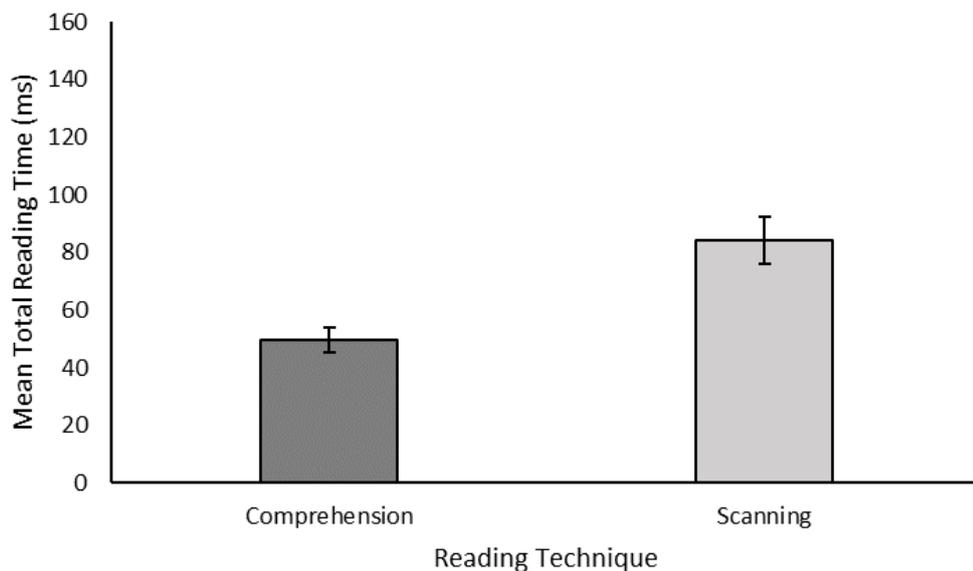


*Figure 9.* Mean total duration of fixations (in seconds) for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Total Reading Time

The mean total reading time was a measure of the average length of time taken from when the participant started reading the section until they had finished reading the section, including any re-reading that took place. This was calculated across all lines of text from each section that was selected for analysis.

Paired samples t-test results showed that there was a significant difference in the mean length of total reading time for comprehension ( $M = 49.79$ ,  $SD = 17.52$ ) and scanning ( $M = 84.36$ ,  $SD = 32.63$ ) conditions;  $t(15) = 5.774$ ,  $p < .0001$ , Cohen's  $d = 1.320$ . Participants took on average significantly longer to read the text when they were scanning the text for information compared to when they were reading the text for comprehension (see *Figure 10*).

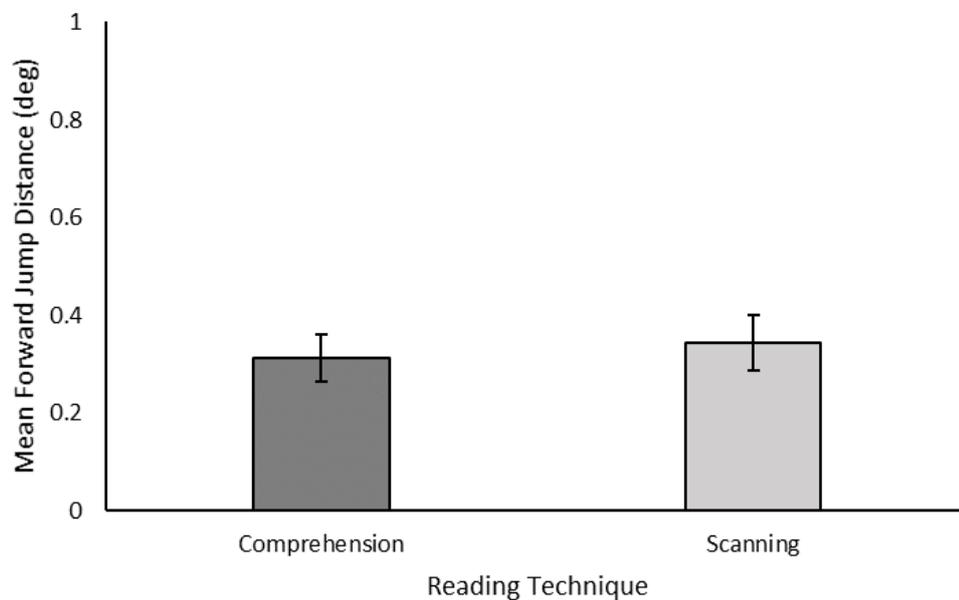


*Figure 10.* Mean total reading time (in milliseconds) for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Forward Jump Distance

The mean forward jump distance was a measure of the average distance from one fixation to the next, moving from left to right, measured in degrees. This was calculated across all lines of text from each section that was selected for analysis.

Paired samples t-test results showed that there was no significant difference between the mean forward jump distance for the comprehension ( $M = 14.14$ ,  $SD = 7.17$ ) and scanning ( $M = 16.16$ ,  $SD = 10.51$ ) conditions;  $t(15) = -.717$ ,  $p = .484$ , Cohen's  $d = .225$ . Therefore, on average, the distance between each of the fixations made by the participants where the eyes were moving from left to right, was about the same when the participant was reading for comprehension and scanning the text for information (see *Figure 11*).

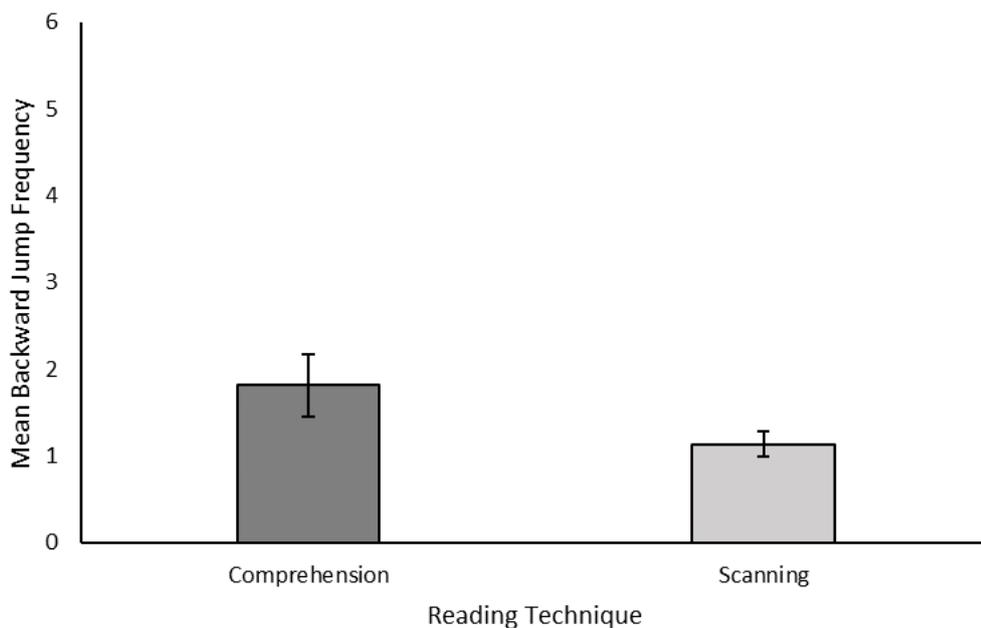


*Figure 11.* Mean forward jump distance (in degrees) for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Number of Backward Jumps

The mean number of backward jumps was a measure of the average frequency of instances of a fixation occurring to the left of the previous fixation point, on the same line of text. This indicates that a participant is re-reading a small part of the text that they have already read or skipped over. This was calculated across all lines of text from each section that was selected for analysis.

Paired samples t-test results showed that there was a significant difference in the mean number of backward jumps made in the comprehension ( $M = 1.81$ ,  $SD = 1.42$ ) and scanning ( $M = 1.14$ ,  $SD = 0.60$ ) conditions;  $t(15) = 2.382$ ,  $p = 0.031$ , Cohen's  $d = .615$ . Therefore, on average, participants made more backwards jumps to a fixation point to the left of the preceding fixation, when they were reading for comprehension compared to when they were scanning the text for information (see *Figure 12*).



*Figure 12.* Mean number of backward jumps for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Previous Line Jumps

The mean number of previous line jumps was a measure of the frequency of instances on average that a fixation occurred on a line of text that was above the previous fixation point. This indicates that a participant is re-reading a larger part of the text that they have already read or skipped over. This was calculated across all lines of text from each section that was selected for analysis.

Paired samples t-test results showed that there was a significant difference in the mean number of previous line jumps made in the comprehension ( $M = 0$ ,  $SD = 0$ ) and scanning ( $M = 0.81$ ,  $SD = 0.66$ ) conditions;  $t(15) = 4.961$ ,  $p < 0.001$ , Cohen's  $d = 1.735$ . Therefore, on average, participants made more backwards jumps to a line of text above the preceding fixation when they were scanning the text for information compared to when they were reading for comprehension (see Figure 13).

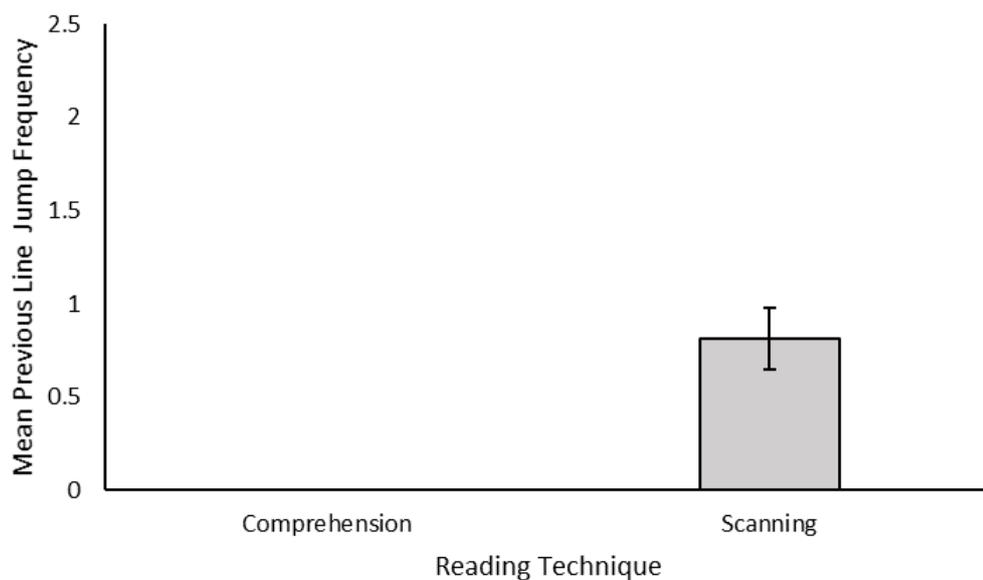
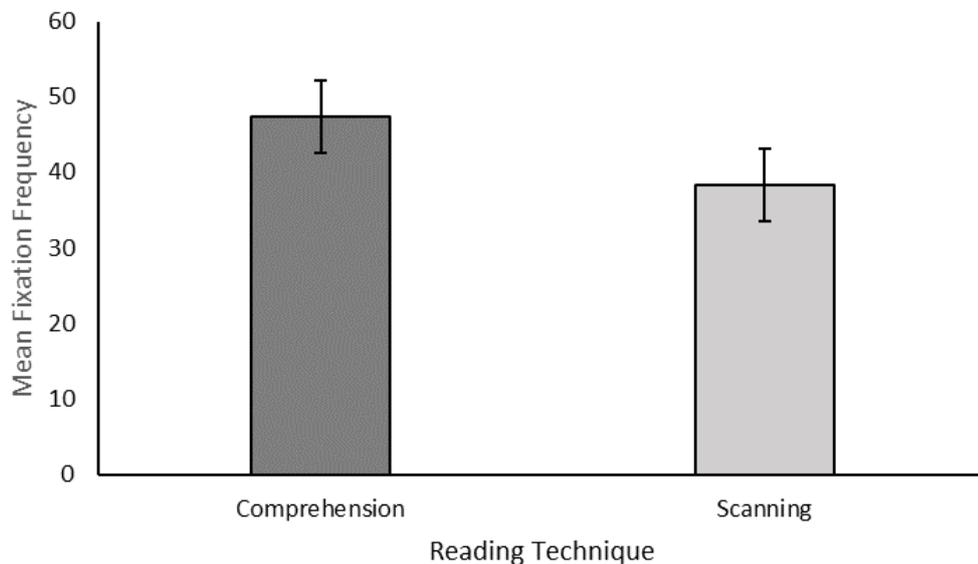


Figure 13. Mean number of previous line jumps for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Number of Fixations

The mean number of fixations was a measure of the average frequency of instances of the eyes being fixed without movement on one location. This was calculated across all lines of text from each section that was selected for analysis.

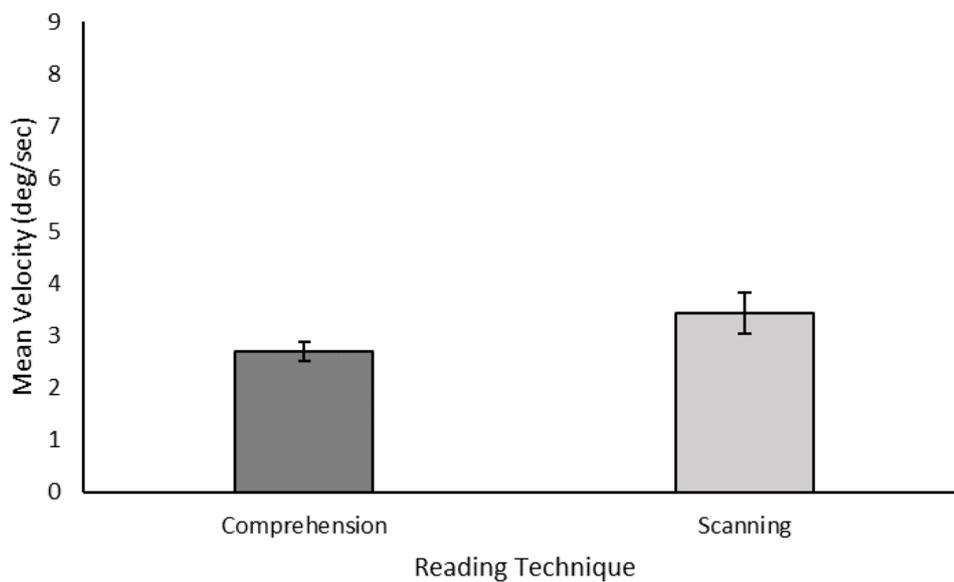
Paired samples t-test results showed that there was a significant difference in the mean number of fixations made in the comprehension ( $M = 47.31$ ,  $SD = 19.33$ ) and scanning ( $M = 38.34$ ,  $SD = 19.36$ ) conditions;  $t(15) = 2.873$ ,  $p = .012$ , Cohen's  $d = .464$ . Therefore, participants made more fixations on the text when they were reading for comprehension compared to when they were scanning the text for information (see *Figure 14*).



*Figure 14.* Mean number of fixations for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## Velocity

Velocity was calculated across the first five lines of text from each section that was selected for analysis. Although not included in the hypotheses, an additional paired samples t-test was conducted to compare the average velocity of the eye movements that were made when reading for comprehension and scanning the text. Results showed that there was no significant difference between the mean velocity of eye movements in the comprehension ( $M = 2.69$ ,  $SD = 0.72$ ) and scanning ( $M = 3.44$ ,  $SD = 1.58$ ) conditions;  $t(15) = -1.661$ ,  $p = .117$ , Cohen's  $d = .611$ . Participants' eyes therefore moved on average at the same pace regardless of whether they were reading for comprehension or scanning the text for information (see *Figure 15*).



*Figure 15.* Mean velocity of eye movements for the Comprehension and Scanning reading technique conditions. Error bars represent standard errors.

## **Individual differences**

Eye movement data appears to vary greatly between participants. Focusing on Mean Fixation Frequency as an example, *Figure 16* depicts the individual differences that are found within the eye tracking measure data.

The highest average number of fixations made when reading for comprehension was made by Participant 9, at 96.6. The lowest average number of fixations made when reading for comprehension was made by Participant 2, at 27. As shown in *Figure 16*, which displays the average number of fixations made by each individual participant for each condition, Because of the large range of average numbers of fixations, some Comprehension scores were lower than some Scanning scores, despite the overall trend being that reading for comprehension had significantly higher average numbers of fixations than scanning the text did. For example, Participants 5, 6 and 8 had a higher number of fixations on average when scanning the text compared to reading for comprehension, which is opposite to the direction of the other participants' results.

Typically, participants who had high scores for reading for comprehension also had high scores for scanning the text, and those who had low scores for reading for comprehension also had low scores for scanning the text. While Participant 9 had the highest average number of fixations when reading for comprehension, they also had the highest average number of fixations, at 84.6, when scanning. Participant 2, who had the lowest average number of fixations when reading for comprehension, had the fourth lowest average number of fixations, at 22.4, when scanning.

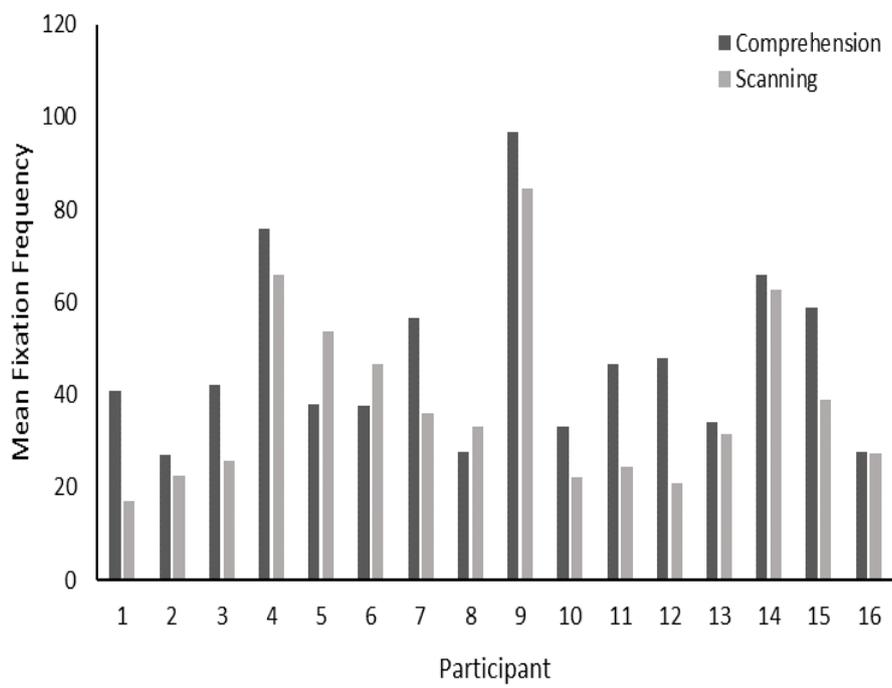


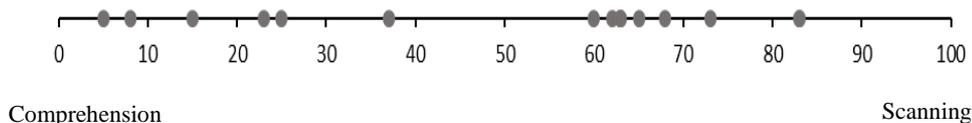
Figure 16. Mean number of fixations made by each participant for the Comprehension and Scanning reading technique conditions.

## Questionnaire Results

Questionnaire answers provided additional information as to some personal demographics and background that may be related to the participants' reading behaviour.

All participants reported that their native language is English and their English fluency was rated at an average of 9.59 out of 10 (Range = 7-10 out of 10) by self-report. Participants estimated that they read in English on average 9.63 hours per week (Range = 1 – 35 hours), and in other unspecified languages on average 0.3 hours per week (Range = 0-2 hours).

Participants were asked to indicate on a scale which reading technique they tend to use more when studying, ranging from “reading for full comprehension” to “scanning to search for particular information”. Six participants (37.5%) marked their usual reading technique as being closer to comprehension, and 10 participants (62.5%) marked their usual reading technique as being closer to scanning (*see Figure 17*)



*Figure 17.* A continuum showing the spread of participants' ratings of their most commonly used reading technique from all Comprehension to all Scanning. Note that some participants' ratings were the same.

Participants were scored on their answers to the comprehension and scanning questions that were part of the reading tasks. For the comprehension condition, the average percentage of correct answers was 95.31% (Range = 50-100%) and for the scanning condition, the average percentage of correct answers was 87.5% (Range = 0-100%).

### **Influence of Other Factors on Eye Movement Results**

The questionnaire results contained five factors relevant to reading that could possibly have been related to the eye movement results collected. A Pearson correlation coefficient was used to determine whether there was a relationship between any of the eye tracking measures and self-reported English fluency level, self-reported number of hours spent reading per week, self-reported usual reading technique used, or accuracy of participant answers to the questions in the comprehension and scanning tasks. Only one correlation was found.

There was a significant negative correlation between the measure of average total reading time in the scanning reading condition and the self-reported average number of hours spent reading per week,  $r = -.512$ ,  $p = .042$ , with a  $R^2 = .262$  (see *Figure 18*).

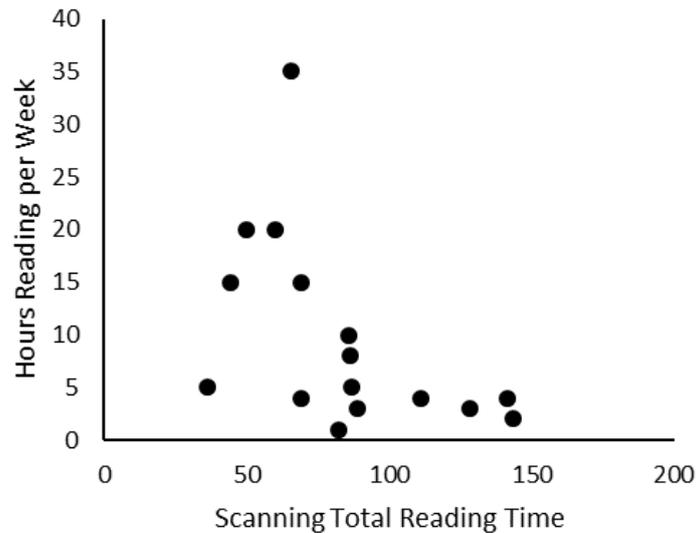


Figure 18. A scatter plot showing the correlation between the total reading time in the scanning condition and number of hours spent reading per week.

There was therefore a possibility that participants' self-reported number of hours spent reading per week may have been a covariate in the relationship between the average total time taken to read the text in the comprehension and scanning conditions. To examine this, a one-way paired samples ANCOVA test was conducted. This test showed that there was no statistically significant difference between the comprehension and scanning conditions when controlling for number of hours spent reading per week,  $F(1,14) = 2.639, p = .127, h_p^2 = .159$ .

There were no other significant correlations or suspected covariate relationships between each of the dependent variable eye movement measures and self-reported English fluency level, self-reported number of hours spent reading per week, self-reported usual reading technique used, or accuracy of participant answers to the questions in the comprehension and scanning tasks.

# Discussion

## Main Findings

The main research question of the present study asked: What are the differences in the eye movements made when reading the text for comprehension compared to scanning the text for information? The following section discusses the results of the study in relation to the hypotheses.

Hypothesis 1 predicted that fixation duration would be higher when reading for comprehension. Hypothesis 1 was not supported, as participants who were reading for comprehension spent on average the same amount of time on each fixation as they did while scanning. It was expected that the comprehension technique would involve longer fixation durations than the scanning technique did, because comprehension is generally associated with readers needing to take longer to fully process the words that they are fixating on (Roy and Crabbe, 2014; Radach et al., 2008). However, it appears that readers required the same amount of time to process words regardless of whether they were scanning the text for particular information or reading for comprehension. It is possible that while reading using either technique, readers, when fixating on a word, took the same amount of processing time on average because they had not mentally distinguished between comprehension and scanning in terms of the amount of cognitive resources that needed to be allocated to each (Jian and Ko, 2017).

Hypothesis 2 predicted that total fixation time would be higher when reading for comprehension. Hypothesis 2 was supported, as participants spent longer on average fixating on the text when they were reading for comprehension compared to scanning. This measure refers to the total sum of the time that participants spent fixating on the text, across all fixations. This was an expected result based on the

research of White et al. (2015). At first glance, Hypothesis 2 being supported while Hypothesis 1 was not seems incongruous: if there is no difference in the average amount of time that was spent on fixations, it could be assumed that there would be no difference in the total amount of time that was spent on fixations. However, the significant difference in total fixation time is linked to the difference found in the average number of fixations being made, which was higher when participants were reading for comprehension compared to when they were scanning the text, supporting Hypothesis 3. Hypothesis 3 predicted that number of fixations would be higher when reading for comprehension. Total fixation time was longer for reading comprehension compared to scanning because there were more fixations being made for reading comprehension, despite the average fixation length not being any longer when reading for comprehension. The higher number of fixations being made when reading for comprehension is supported, as Krieber et al. 2016, suggested that the number of fixations made is related to the difficulty of the reading task, while reading for comprehension is considered to require more cognitive processing and be higher in difficulty (Kirsch and Guthrie, 1984, Radach et al., 2008).

Hypothesis 4 predicted that number of backwards saccades (regressions on the same line) would be higher when reading for comprehension. Hypothesis 4 was supported, as the number of backwards saccades was higher for participants when they were reading for comprehension compared to scanning the text, as found in previous research (Roy and Crabbe, 2014; Radach et al., 2008). It is expected that readers return to previous words that were not fully processed during the first pass reading if they have the goal of comprehension of the text, rather than scanning for particular information that is relevant for answering a question.

Hypothesis 5 predicted that total reading time would be higher when reading for comprehension. Hypothesis 5 was not supported, as the total reading time was longer for those who were scanning the text compared to reading for comprehension, which was the opposite of what was expected (Jian and Ko, 2017). Again, this unexpected result may be linked to the result of another measure. Although total fixation time was longer when reading for comprehension, the extra time taken when scanning the text appears to be due to the number of re-reads, or fixations made on a previous line, being higher when participants were scanning the text. This was an unexpected result and Hypothesis 6 was therefore not supported. Hypothesis 6 predicted that number of rereads (fixations on previous line) would be higher when reading for comprehension. It had been expected that the number of re-reads would be higher when the participant was reading for comprehension, due to the comprehension condition being more difficult and requiring more processing to complete (Salmeron et al., 2016; Roy and Crabbe, 2014, Radach et al., 2008).

Hypothesis 7 predicted that jump distance would be higher when scanning the text. Hypothesis 7 was also not supported, as the forward jump distance for participants who were reading for comprehension was the same on average as the forward jump distance when scanning the text. It was unexpected that participants would jump in equal distances towards the next fixation regardless of the reading technique that they were using, due to scanning being expected to be characterised by larger jump distances as the reader skipped ahead in the text searching for relevant information (Just and Carpenter, 1980; Duggan and Payne, 2011).

Additionally, no significant difference was found between the mean velocity of eye movements when reading for comprehension and scanning the text, and this

serves as evidence that eye velocity did not contribute towards the recorded length of time taken to read the text.

It can be concluded that there are differences between the eye movements made when reading the text for comprehension and scanning the text for information, however these differences are not entirely as expected.

The results of the present study demonstrate that readers skip equal distances toward the next fixation point and spend on average the same amount of time looking at each fixation point, regardless of the reading technique that they are using. Reading for comprehension of the text was best characterised by the larger numbers of fixations made, contributing towards a longer total fixation time, and the larger numbers of backwards saccades made compared to those that were made when scanning the text.

The larger number of re-reads may be the best characterisation of the scanning technique shown in this experiment, as participants were searching around the text more to scan for information, but rather than jumping to text further ahead as expected, participants re-read earlier parts of the text to search for information. These results may be evidence that participants were not scanning the text in the expected order (left to right, top to bottom of the page) as much as they were when reading for comprehension. The extra time then spent looking around the text for information likely contributed to the longer reading time for scanning the text compared to reading for comprehension. Another influencing factor in this relationship may be the fact that participants were not able to return to the previous page once they had moved on to the second page, meaning that they may have spent longer rereading sections of the first page until they were satisfied that the answer they were scanning the text for was not on the first page.

It is possible that some measures of eye movement are more useful or powerful than others in demonstrating the difference between the techniques of reading for comprehension and scanning the text for information. For example, the difference between the comprehension and scanning techniques may have a more obvious effect on backwards saccades, which had a significant difference under the two reading conditions, than it had on fixation duration, which had no significant difference under the two reading conditions.

Kaakinen et al. (2018) stated that eye movement measures such as fixation duration are not sufficient to contribute towards understanding of the cognitive processes of reading. Based on the present study, the measures of eye movement which showed a significant difference between the two reading techniques (number of fixations, number of regressions, number of rereads and total fixation duration) may be more useful than the measures which showed no difference (jump distance and average fixation duration) for studying reading behaviour.

### **Self-Report Questionnaire**

Questionnaire responses gave an indication of what factors may have affected the participants' reading behaviour during the experiment tasks. Responses indicated that the participants' usual reading behaviour varied greatly, with some reading many more hours per week, the highest being 34 hours per week, than others did, the lowest being one hour per week. The technique that participants reported that they tended to use most frequently when reading also varied greatly, as seen in *Figure 17* with a wide range of responses on the continuum from mainly reading for comprehension to mainly scanning the text for information. The variability in these responses may suggest that participants varied in their experience and comfort with reading, and furthermore with using either a

comprehension or scanning technique to read, which may have affected their individual eye movement results during the reading tasks. For this reason, other reading research, such as that undertaken by Kirsch (1984), asked participants whether they usually read for comprehension or scanned text, as a method of linking previous reading experience to reading performance during the experimental task.

There appeared to be one covariant: number of hours spent reading, which had an effect on the significance of the difference in the time taken to read the text in the Comprehension and Scanning Conditions. Although more research is required in order to better understand this relationship, it appears that the previous experience that a reader has can have an influence on the amount of time it takes them to read a section of text. Greater reading experience may contribute towards 'closing the gap' between different reading techniques, such as comprehension and scanning, and the way that these techniques are approached by the reader.

It should be noted that participants self-reported varying levels of English language fluency, with a range from seven to 10 out of 10, despite all participants also reporting that English was their native language. Native speakers would generally be assumed to be fully fluent in the language, however, participants may have instead interpreted the fluency question as relating to their literacy skills or abilities.

### **Individual Differences**

Henderson and Luke (2014) conducted a study which investigated whether the individual differences in eye movements made when reading were stable within individuals and over time. In this study, participants read newspaper or magazine passages across several trials on separate days. The results showed that eye

movements such as mean fixation duration and jump distance varied between participants but were constant within each trial of the same participant over time.

The authors warn that although eye movement research usually focuses on the variability that is caused by changing stimuli, it is important to take into account the variability that is caused by individual differences in eye movements. These differences between participants that are not related to the changes in stimuli play a key part in the outcomes of eye tracking experiments.

The large individual differences between the participants in the present study likely have a strong effect on the variability of the eye movements that were recorded and as such, are worth considering in more detail. The range of results that were found for most of the dependent measures within each condition were quite large, despite the participants reading the same text, using the same technique under the same experimental conditions.

Participants who had high scores for reading for comprehension also tended to have high scores for scanning the text, and those who had low scores for reading for comprehension also tended to have low scores for scanning the text. This finding is similar to what was identified by Henderson and Luke (2014, p. 1397), who claimed that, "Individuals who were relatively long fixators in one task tended to be relatively long fixators in other tasks, and conversely, people who were relatively short fixators in one task tended to be relatively short fixators in other tasks." Krieger et al (2016) also reported stable individual differences across reading tasks from participants in their research.

Occasionally, however, participants did have results in the opposite direction to the trend, so that one condition took longer than the other when it wasn't expected to. These results were unexpected but were not strong enough to affect the overall

significance of the higher number of fixations for the Comprehension condition. Results which vary due to individual differences show the importance of having a large enough sample size so as to not mask the effect of the overall trend.

It was important that this experiment utilised a within-subjects design, mainly for the reason that if participants had either only read for comprehension or only scanned the text, it would be difficult to compare the eye movements used for each reading technique because there is so much variability to be accounted for by individual differences. In comparing each participant's eye movements when reading for comprehension with the same participant's eye movements when scanning the text, it is certain that any individual differences have been eliminated from having an effect.

### **Applications of the Findings**

There is a lack of published information on the norms for eye movements when reading. Based on the results of the present research, a basic guideline may be created for the normal eye movements that are to be expected when the average, educated adult with no processing or vision difficulties is reading. For example, the average time taken to read a line, the average time taken to fixate on a word, the average distance of forward saccades, the average number of regressions, et cetera, along with standard deviations, may be used as measurements to which comparisons are made.

People who are uncertain of how their comprehension or scanning skills compare to the average reader may compare their eye movement measurements with the results of the present study. Furthermore, these eye movement norms may be used in diagnosing people with reading or processing issues, such as dyslexia. As Nilsson Benfatto et al. (2016) found, differences in progressive fixations,

progressive saccades, regressive fixations and regressive saccades indicate the possibility of reading difficulties, while Rayner (2006) identified longer fixations, shorter saccades, and more backward regressions as being measurements of interest for identifying dyslexic or low skilled readers.

It is also possible that eye movement patterns could be taught to people who are seeking to improve their comprehension or scanning skills, such as learners of English as a second or foreign language, students who would like to gain better study techniques, people with reading difficulties, or even children who are learning to read for the first time.

It has been suggested that eye movement training could benefit people with dyslexia (Kapoula, 2012), and students (Salmeron et al., 2008). Salmeron et al. (2016) suggest that eye movement measures may be used to create modelling videos which demonstrate the eye movements of highly-skilled readers. Using this method, the results of the present study could be used to create a video demonstrating the normal eye movements made while reading for comprehension or scanning text for information, and shown to people who may then mimic these eye movement patterns in their own reading in order to teach them the most effective eye movements to use when reading.

### **Limitations**

Due to the use of a repeated measures, within-subjects design for the present experiment, the factors which affect reading behaviour are not expected to have had an effect on the data collected, as participants' responses were only compared to their own responses between conditions. Any particular differences which apply to the individual participant, such as skill level, only exist within the individual data

and do not affect the overall data. Factors which may affect the overall variability of the data due to large individual differences are discussed here.

The difficulty of the reading task has been shown by other research to have an influence on reading behaviour. Rayner et al. (2006), found that the difficulty of a reading task was responsible for much of the variability in the fixation length, saccade length and number of regressions.

A limitation of the present study is that the level of difficulty of the tasks as perceived by the participants of the present research was not measured, making it a factor of an unknown level of influence in the individual eye movement results recorded. The difficulty level of the reading task for the participants could be partially measured using the accuracy scores of their answers to the comprehension and scanning questions. In fact, while the majority of the participants answered the questions correctly, one of the participants was unable to provide any answer to the scanning question. This may be evidence that this participant found the task more difficult than some of the other participants did.

However, in order to understand the differences between participants in the difficulty of the task, it would have been more effective to ask the participants to rate the difficulty of the task. This could have been achieved by adding an extra question to the questionnaire booklet for the participants to answer after finishing the reading task. Individual difficulty ratings could then be connected to individual eye tracking measures to determine whether the perceived difficulty level had had an effect on the reading behaviour that was used when scanning the text or reading for comprehension. The within-subjects design of the experiment eliminates the potential issue of the difficulty factor having an influence on the significant differences found between the two reading conditions. The difficulty of the task

may however serve as a partial explanation for the large range of results between participants.

However, the fact that the average fixation duration lengths were not significantly different for the two reading techniques in the present study indicated that readers may not have felt the need to allocate more cognitive resources to one reading technique or the other, possibly due to the reading tasks being equal, as people have been shown to fixate for longer during a task when it is more difficult, requiring the allocation of more cognitive resources (Jian and Ko 2017).

Another limitation of the present experiment is that the reading skill level of the participants was not measured. The skill level of readers has been shown to be related to their eye movements when reading. Highly skilled readers showed a reduced number of fixations per word and total number of saccades, and reduced jump distances, while low skilled readers showed longer fixation durations, during speed reading and comprehension tests, according to Krieber et al. (2016). Salmeron et al. (2016) also found that reading behaviour differed with skill level, including the finding that highly skilled readers reread the text fewer times and read the text more quickly during a scanning task. This may mean that readers at a higher skill level were better at using the scanning technique to their advantage.

As the skill level of the readers was not measured or controlled for, it is unclear whether some of the eye movements made were affected by the skill level of the reader, particularly where an individual participant may have a higher comprehension skill level than their scanning skill level, or vice versa. Their frequency of rereads, fixations and saccades, and jump distances, may have then been longer or shorter when using one technique or the other, not because the nature of the reading technique itself requires it, but because their skill in reading using that technique is better than when reading using the other technique.

Again, although the accuracy of the reading task answers given by the participants of the present study could be used as an indication of their skill level, a type of comprehension and scanning skill test would be better at predicting the skill level of the participant. Reading test scores could then be used to rule out the possibility of the individual eye movements for each condition being different due to the skill level of the participants in using different reading techniques.

The generalizability of the eye movement data collected during the present study may also be a limitation. It was assumed that as the participants were all university students, they would have adequate reading skills for carrying out the experimental task. However, the results collected may not generalize well to the wider population. It is especially important to consider that those who may be interested in improving their comprehension or scanning skills using the results of the present study may not have the same level of reading ability and experience as the university student participants here, and their eye movements may differ even when still 'normal'. The eye movement results may also not generalize well to children or the elderly – separate research into the eye movements of these groups when reading using different reading techniques may be more useful.

### **Future Research**

Readers are unlikely to be fully aware of the particular eye movements that they are making, as reading is a habit formed early in life. However, some reading behaviour associated with particular reading techniques may be known to the reader.

In order to be certain about how much of the eye movement used for the comprehension and scanning techniques was consciously decided upon by the reader, more qualitative research should be undertaken. This follows the method used by Bax (2016) where participants were interviewed about their reading

behaviour during comprehension and scanning tasks, which could then be matched up to their eye tracking data from the task. This would allow further insight into whether the eye movements that are used for different reading techniques are teachable, and to what degree.

Participants would then be able to tell the researcher about decisions that were consciously made to reread parts of the text, look for longer at a particular section, jump ahead, or even read the text out of order, along with their reasoning for these decisions.

As well as research by Bax (2016), Miller (2015) also suggested that self-report and thinking aloud methods be used alongside eye tracking research as a mode of triangulation of the findings. Additionally, Roy and Crabbe (2014) suggested that students engaging in this type of self-reflection on the techniques that they used to read may be effective in helping them to consider the reading techniques that they are able to use to best comprehend or scan the text.

Many other factors could be modified in future research into reading techniques, to determine how the eye movements change accordingly. The level of difficulty of the text may be varied to observe whether the differences in eye movements when using different reading techniques becomes more or less pronounced. Varying difficulty levels may be attained by modifying the frequency, familiarity or length of the words used (Radach, 2006; Juhasz and Rayner, 2003; Korneev et al., 2017), or organising the text in a different way (Dos Santos Lonsdale, 2014).

More research could also be carried out on the power, usefulness and effectiveness of the eye movement measurements that are used to determine differences in reading processing, and whether some of these may be better than

others for creating a model of how comprehension and scanning processes are carried out differently in the brain.

If the perceived difficulty of the reading task was measured and it was found to be quite low or average, it would be interesting to increase the difficulty of the comprehension and scanning tasks to examine whether a clearer difference between the two techniques would become apparent or whether there would be no difference from the results of the present study.

## Conclusions

The eye movements involved when reading for comprehension are different from the eye movements that are involved when scanning the text for information, as characterised by a longer total fixation time on average, a higher average number of fixations, and a higher average number of backwards saccades when reading for comprehension; and by a longer total reading time on average and higher number of average rereads when scanning the text for information. The jump distances and average single fixation durations show no change between the two reading techniques. It is unclear whether some eye movements may be more powerful than others at determining the difference between reading techniques, and further research could be carried out to answer this question. However, it is certain that eye movements are useful measures and can be used successfully to differentiate between reading techniques.

Individual differences have a strong presence in the findings of this research. It is important to note that different factors such as skill level, text familiarity, attention and engagement, as well as many other factors, may contribute towards the large range of individual differences in results that are obtained from reading research.

Knowledge of the different eye movements that are involved in comprehension and scanning reading techniques may be helpful for those who wish to improve their reading skills, such as students, learners of English as a second language, children learning to read for the first time and people who have abnormal reading patterns due to reading difficulties such as dyslexia. It is possible that the findings of this research may be used for teaching better awareness of the eye movements that are most efficient for different types of reading.

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# Appendix A



## Comparing the Eye Movement Patterns of Different Reading Techniques

The main aim of this study is to examine the difference in eye movement patterns when participants are reading using different reading techniques.

- 1) You will receive instructions regarding the desk-mounted eye tracker that will record your eye movements.
- 2) You will be shown a page of text and asked to read it. You will be presented with some questions about what you have read, which will appear either before or after you read the text. Enter your answer to each question on the paper provided.
- 3) You will then be asked to fill out a short questionnaire about your reading habits.

The session will take approximately 30 minutes.

All recorded data will be anonymous and be stored with no personal information attached. Electronic data will be stored on a secure server in a password protected file and can only be accessed by the researcher and supervisors. Data will be kept for a maximum of five years. The findings will be reported and analysed for the purpose of a ~~Masters~~ thesis.

You can withdraw from the experiment at any time without penalty. If you have any questions about the study please contact the researcher Kerriane Lindsey ([kmlindsey12@gmail.com](mailto:kmlindsey12@gmail.com)) or her supervisor Associate Professor John Perrone ([jpnz@waikato.ac.nz](mailto:jpnz@waikato.ac.nz)).

The study has received Ethics approval (#18:24) from the School of Psychology Research and Ethics Committee at the University of Waikato. If you have any concerns about the ethical conduct of this research please contact the convenor Dr Rebecca Sargisson ([rebeccas@waikato.ac.nz](mailto:rebeccas@waikato.ac.nz))

# Appendix B



## CONSENT FORM

### Research Project: Comparing the Eye Movement Patterns of Different Reading Techniques

Please complete the following checklist. Tick (✓) the appropriate box for each point.	YES	NO
1. I have read the Participant Information Sheet (or it has been read to me) and I understand it.		
2. I have been given sufficient time to consider whether or not to participate in this study		
3. I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet		
4. I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without penalty		
5. I have the right to decline to participate in any part of the research activity		
6. I know who to contact if I have any questions about the study in general.		
7. I understand that the information supplied by me could be used in future academic publications.		
8. I understand that my participation in this study is confidential and that no material which could identify me personally will be used in any reports on this study.		
I wish to receive a copy of the findings		

#### Declaration by participant:

I agree to participate in this research project and I understand that I may withdraw at any time. If I have any concerns about this project, I may contact the convenor of the Psychology Research and Ethics Committee (Dr Rebecca Sargisson, phone 07 837 9580, email: [rebecca.sargisson@waikato.ac.nz](mailto:rebecca.sargisson@waikato.ac.nz))

Participant's name (Please print): \_\_\_\_\_

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

#### Declaration by member of research team:

I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it. I believe that the participant understands the study and has given informed consent to participate.

Researcher's name (Please print): \_\_\_\_\_

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

# Appendix C

## CHAPTER I

### THE QUESTION STATED

THE first thought that men had concerning the heavenly bodies was an obvious one: they were lights. There was a greater light to rule the day; a lesser light to rule the night; and there were the stars also.

In those days there seemed an immense difference between the earth upon which men stood, and the bright objects that shone down upon it from the heavens above. The earth seemed to be vast, dark, and motionless; the celestial lights seemed to be small, and moved, and shone. The earth was then regarded as the fixed centre of the universe, but the Copernican theory has since deprived it of this pride of place. Yet from another point of view the new conception of its position involves a promotion, since the earth itself is now regarded as a heavenly body of the same order as some of those which shine down upon us. It is amongst them, and it too moves and shines—shines, as some of them do, by reflecting the light of the sun. Could we transport ourselves to a neighbouring world, the earth would seem a star, not distinguishable in kind from the rest.

But as men realized this, they began to ask: “Since this world from a distant standpoint must appear as a star, would not a star, if we could get near enough to it, show itself also as a world? This world teems with life; above all, it is the home of human life. Men and women, gifted with feeling, intelligence, and character, look upward from its surface and watch the shining members of the heavenly host. Are none of these the home of beings gifted with like powers, who watch in their turn the movements of that shining point which is our world?”

This is the meaning of the controversy on the Plurality of Worlds which excited so much interest some sixty years ago, and has been with us more or less ever since. It is the desire to recognize the presence in the orbs around us of beings like ourselves, possessed of personality and intelligence, lodged in an organic body.

This is what is meant when we speak of a world being “inhabited.” It would not, for example, at all content us if we could ascertain that Jupiter was covered by a shoreless ocean, rich in every variety of fish; or that the hard rocks of the Moon were delicately veiled by lichens. Just as no richness of vegetation and no fulness and complexity of animal life would justify an explorer in describing some land that he had discovered as being “inhabited” if no men were there, so we cannot rightly speak of any other world as being “inhabited” if it is not the home of intelligent life. If the life did not rise above the level of algæ or oysters, the globe on which they flourish would be uninhabited in our estimation, and its chief interest would lie in the possibility that in the course of ages life might change its forms and develop hereafter into manifestations with which we could claim a nearer kinship.

On the other hand, of necessity we are precluded from extending our enquiry to the case of disembodied intelligences, if such be conceived possible. All created existences must be conditioned, but if we have no knowledge of what those conditions may be, or means for attaining such knowledge, we cannot discuss them. Nothing can be affirmed, nothing denied, concerning the possibility of intelligences existing on the Moon or even in the Sun if we are unable to ascertain under what limitations those particular intelligences subsist. Gnomes, sylphs, elves, and fairies,

and all similar conceptions, escape the possibility of discussion by our ignorance of their properties. As nothing can be asserted of them they remain beyond investigation, as they are beyond sight and touch.

The only beings, then, the presence of which would justify us in regarding another world as “inhabited” are such as would justify us in applying that term to a part of our own world. They must possess intelligence and consciousness on the one hand; on the other, they must likewise have corporeal form. True, the form might be imagined as different from that we possess; but, as with ourselves, the intelligent spirit must be lodged in and expressed by a living material body. Our enquiry is thus rendered a physical one; it is the necessities of the living body that must guide us in it; a world unsuited for living organisms is not, in the sense of this enquiry, a “habitable” world.

The discussion, as it was carried on sixty years ago by Dr. Whewell and Sir David Brewster, was essentially a metaphysical, almost a theological one, and it was chiefly considered in its supposed relationship to certain religious conceptions. It was urged that it was derogatory to the wisdom and goodness of the Creator to suppose that He would have created so many great and glorious orbs without having a definite purpose in so doing, and that the only purpose for which a world could be made was that it might be inhabited. So, again, when Dr. A. R. Wallace revived the discussion in 1903, he clearly had a theological purpose in his opening paper, though he was taking the opposite view from that held by Brewster half a century earlier.

For myself, if there be any theological significance attaching to the solving of this problem, I do not know what it is. If we decide that there are very many inhabited worlds, or that there are few, or that there is but one—our own—I fail to see how it should modify our religious beliefs. For example: explorers have made their way across the Antarctic continent to the South Pole but have found no “inhabitant” there. Has this fact any theological bearing? or if, on the contrary, a race of men had been discovered there, what change would it have made in the theological position of anyone? And if this be so with regard to a new continent on this earth, why should it be different with regard to the continents of another planet?

The problem therefore seems not to be theological or metaphysical, but purely physical. We have simply to ask with regard to each heavenly body which we pass in review: “Are its physical conditions, so far as we can ascertain them, such as would render the maintenance of life possible upon it?” The question is not at all as to how life is generated on a world, but as to whether, if once in action on a particular world, its activities could be carried on.

## CHAPTER II

### THE LIVING ORGANISM

A WORLD for habitation, then, is a world whereon living organisms can exist that are comparable in intelligence with men. But “men” presuppose the existence of living organisms of inferior grades. Therefore a world for habitation must first of all be one upon which it is possible for living organisms, as such, to exist.

It does not concern us in the present connection how life first came into existence on this planet. It is sufficient that we know from experience that life does exist here; and in whatsoever way it was first generated here, in that same way we may consider that it could have been generated on another planet.

Nor need any question trouble us as to the precise line of demarkation to be drawn between inorganic and organic substances, or amongst the latter, between plants and animals. These are important subjects for discussion, but they do not affect us here, for we are essentially concerned with the highest form of organism, the one furthest from these two dividing lines.

It suffices that living organisms do exist here, and exist under well-defined conditions. Wanting these conditions, they perish. We can, to a varying degree, determine the physical conditions prevailing upon the heavenly bodies, and we can ascertain whether these physical conditions would be favourable, unfavourable, or fatal to the living organism.

What is a living organism? A living organism is such that, though it is continually changing its substance, its identity, as a whole, remains essentially the same. This definition is incomplete, but it gives us a first essential approximation, it indicates the continuance of the whole, with the unceasing change of the details. Were this definition complete, a river would furnish us with a perfect example of a living organism, because, while the river remains, the individual drops of water are continually changing. There is then something more in the living organism than the continuity of the whole, with the change of the details.

An analogy, given by Max Verworn, carries us a step further. He likens life to a flame, and takes a gas flame with its butterfly shape as a particularly appropriate illustration. Here the shape of the flame remains constant, even in its details. Immediately above the burner, at the base of the flame, there is a completely dark space; surrounding this, a bluish zone that is faintly luminous; and beyond this again, the broad spread of the two wings that are brightly luminous. The flame, like the river, preserves its identity of form, while its constituent details—the gases that feed it—are in continual change. But there is not only a change of material in the flame; there is a change of condition. Everywhere the gas from the burner is entering into energetic combination with the oxygen of the air, with evolution of light and heat. There is change in the constituent particles as well as change of the constituent particles; there is more than the mere flux of material through the form; there is change of the material, and in the process of that change energy is developed.

A steam-engine may afford us a third illustration. Here fresh material is continually being introduced into the engine there to suffer change. Part is supplied as fuel to the fire there to maintain the temperature of the engine; so far the illustration is analogous to that of the gas flame. But the engine carries us a step further, for part of the material supplied to it is water, which is converted into steam by the heat of

the fire, and from the expansion of the steam the energy sought from the machine is derived. Here again we have change in the material with development of energy; but there is not only work done in the subject, there is work done by it.

But the living organism differs from artificial machines in that, of itself and by itself, it is continuously drawing into itself non-living matter, converting it into an integral part of the organism, and so endowing it with the qualities of life. And from this non-living matter it derives fresh energy for the carrying on of the life of the organism.

The engine and the butterfly gas flame do not give us, any more than the river, a complete picture of the living organism. The form of the river is imposed upon it from without; the river is defined by its bed, by the contour of the country through which it flows. The form and size of the flame are equally defined by exterior conditions; they are imposed upon it by the shape of the burner and the pressure of the gas passing through it. The form of the engine is as its designer has made it. But the form of the living organism is imposed upon it from within; and, as far as we can tell, is inherent in it. Here is the wonder and mystery of life: the power of the living organism to assimilate dead matter, to give it life and bring it into the law and unity of the organism itself. But it cannot do this indiscriminately; it is not able thus to convert every dead material; it is restricted, narrowly restricted, in its action. "One of the chief characteristics of living matter is found in the continuous range of chemical reactions which take place between living cells and their inorganic surroundings. Without cease certain substances are taken up and disappear in the endless round of chemical reactions in the cell. Other substances which have been produced by the chemical reactions in living matter pass out of the cell and reappear in inorganic nature as waste products of the life process. The whole complex of these chemical transformations is generally called Metabolism. Inorganic matter contrasts strikingly with living substance. However long a crystal or a piece of metal is kept in observation, there is no change of the substance, and the molecules remain the same and in the same number. For living matter the continuous change of substances is an indispensable condition of existence. To stop the supply of food material for a certain time is sufficient to cause a serious lesion of the life process or even the death of the cell. But the same happens when we hinder the passing out of the products of chemical transformation from the cell. On the other hand, we may keep a crystal of lifeless matter in a glass tube carefully shut up from all exchange of substance with the external world for as many years as we like. The existence of this crystal will continue without end and without change of any of its properties. There is no known living organism which could remain in a dry resting state for an infinitely long period of time. The longest lived are perhaps the spores of mosses which can exist in a dry state more than a hundred years. As a rule the seeds of higher plants show their vital power already weakened after ten years; most of them do not germinate if kept more than twenty to thirty years. These experiences lead to the opinion that even dry seeds and spores of lower plants in their period of rest of vegetation continue the processes of metabolism to a certain degree. This supposition is confirmed by the fact that a very slight respiration and production of carbonic acid can be proved when the seeds contain a small percentage of water. It seems as if life were weakened in these plant organs to a quite imperceptible degree, but never, not even temporarily, really suspended.

"Life is, therefore, quite inseparable from chemical reactions, and on the whole what we call life is nothing else but a complex of innumerable chemical reactions in the living substance which we call protoplasm."

## Appendix D

First, we will calibrate the eye tracker so that it can track your eye movements. You will see a series of small circles on the screen. Please look at each circle and press the space bar when you are looking at it.

Press the space bar to continue to calibration.

### Comprehension 1 and Comprehension 2

You will now be presented with a chapter of text. Please read it carefully and make sure that you understand it. You will be asked questions about your comprehension after you finish reading. There are two pages – please press the space bar to go on to the second page after you have finished reading the first page.

### Scanning 1

You will now be presented with a chapter of text. There are two pages – please press the space bar to go on to the second page after you have finished reading the first page.

Please scan the text to find the answers to these questions:

- 1) In what year did Dr. A. R. Wallace revive the discussion on the theological concepts of other worlds?

### Scanning 2

You will now be presented with a chapter of text. There are two pages – please press the space bar to go on to the second page after you have finished reading the first page.

Please scan the text to find the answers to these questions:

- 1) How is metabolism described?

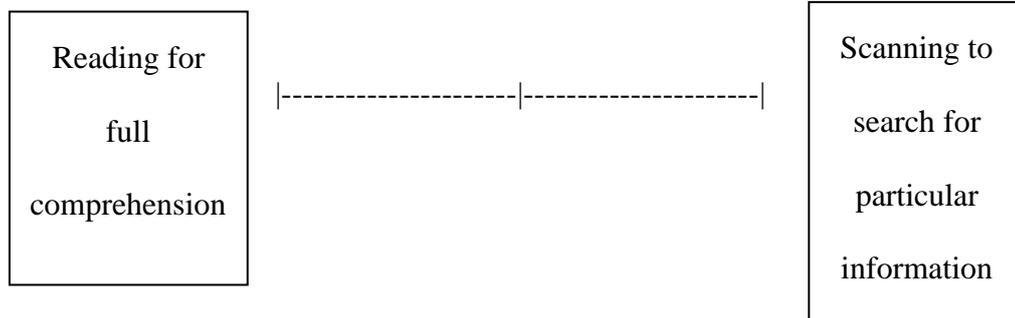
# Appendix E

## Demographic Questions:

1. What is your age? \_\_\_\_\_
2. What is your gender? \_\_\_\_\_
3. What is your level of English fluency? 1 2 3 4 5 6 7 8 9 10
4. What is your native language (mother tongue)?  
\_\_\_\_\_
5. Do you read in this language? \_\_\_\_\_

## Reading Questions:

1. a) How many hours per week on average do you read in English? (books, articles, textbooks, e-books, etc.)? \_\_\_\_  
  
b) How many hours per week on average do you read in languages other than English? \_\_\_\_
2. When studying, which reading technique do you tend to use more? Mark your answer on the scale:



## Other Comments: