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Learning from Hypertext: Navigation, Comprehension, and Working Memory in University Students



Thesis submitted to the School of Psychology, Queen's University, Belfast, in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

February 2021

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Abstract

Reading text from an electronic screen has become prevalent for both recreation and education, with hypertext establishing itself as a large part of the digital reading corpus. Despite hypertext research taking place for around three decades, questions remain about the reading processes involved in this format, whether individual reader differences are beneficial or detrimental to learning, and how to facilitate navigation and comprehension. Three introductory chapters review the current research literature on reading comprehension across study media, and explore the cognitive processes for reading and navigating texts in the digital era. In four experiments, this thesis investigates hypertext learning in university students, focusing on navigation, comprehension, and working memory. The experiments find that deep, inferential, reading comprehension is weaker in hypertext than in print text, with low prior knowledge and lower working memory ability hypertext readers being especially disadvantaged. Equivalence between print and scrolling text performance indicates specific challenges in hypertext (e.g., disorientation, disruption of comprehension processes) are responsible for differences between study media, rather than more general screen inferiority effects. This thesis concludes that, while hypertext presents unique challenges to learning, novel hypermedia features may help overcome them. Evidence for this is in the final experiment, where provision of a dynamic graphical overview facilitates navigation and comprehension in hypertext. Print text is unlikely to make a resurgence in classrooms, so research should continue to explore differences between study media and ways to improve comprehension of hypertext.

Keywords: study media, hypertext, navigation, reading comprehension, reading strategies.

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Marc Edwards

Queen's University, Belfast

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Chapter 1: Introduction

1.1 Reading in the Digital Age

From the earliest Cuneiform writing systems developed by the Sumerians of Mesopotamia around 3000 BC to the ubiquitous electronic devices of modern day, humans have consistently developed creative ways to record information for reading. Following the advent of paper approximately 2000 years ago, the material quickly spread through China, the Middle East, India, and later the rest of the world where it eventually became the primary source for reading (Shenoy & Aithal, 2016). The early scroll presented writing on a continuous roll of paper, but this was soon replaced by the codex which was made up of several pages bound together to facilitate convenient access to precise points in the text. In 1452, Gutenberg's printing press revolutionised reading technology by allowing for mass production of printed materials, resulting in an exponential growth in literacy skills (Keirns, 2018). This format has remained largely the same through to the modern era, where books have long dominated the landscape of printed text (Darnton, 2007). However, relatively recent technological advances have resulted in a multitude of electronic sources with screens for reading including computers, tablets, mobile phones, and e-readers (Mangen et al., 2019). As a result, reading text from an electronic screen has become increasingly prevalent for both recreation and education (Kong et al., 2018; Picton, 2014; Precel et al., 2009).

There are many examples of the recent emergence of screen reading. For instance, Barron's (2011) research found that Amazon.com, the world's largest online retailer, had begun to sell more e-books than print-text books at the beginning of the last decade. Furthermore, Perrin's (2016) descriptive analysis of research

conducted by the Pew Research Centre (2016) in the five-year period between 2011 and 2016 found that the share of Americans who read e-books on a regular basis increased from 17% to 28%. Despite findings that the rates of digital reading were rapidly increasing during this period, Perrin's (2016) analysis also noted that print reading remained at the centre of the book-reading landscape as a whole. More recently, Perrin (2019) conducted a further descriptive analysis of the Pew Research Centre's (2019) updated research on Americans' reading activity. It was revealed that while the share of Americans who had read a book in the last year (72%) was largely unchanged since 2012, there was a further increase in e-book reading and audiobook listening during this period. These findings highlight the variety of ways in which individuals consume books today. Print reading has remained relatively stable, whereas screen reading and alternative ways to consume books are increasingly becoming more prevalent.

Increasing exposure to electronic screens can be seen particularly in children; the National Literacy Trust's annual literacy survey found that the number of children who owned an e-reader rose from 20% to 30% between 2012 and 2013, and that tablet use at home by children aged 5 to 15 almost tripled during this period (Picton, 2014). Furthermore, 97% of surveyed children had access to electronic devices, with the same proportion having access to the internet at home. The most recent National Literacy Trust's research surveyed 56,906 children in the U.K. between January to March 2019 (Clark & Teravainen-Goff, 2019). It found a further increase in screen reading from the following year, although print formats still dominated children and young people's reading in 2019. Over 80% of participants reported that they read websites, instant messages, and text messages (formats that can only be read on screen) at least once a month. These studies are consistent with

others' findings that approximately 90% of young adolescents are online and using multiple electronic devices to look up information both at school and at home (Hahnel et al., 2015).

Schools are also increasingly beginning to modernise their methods with a shift in emphasis away from print textbooks towards 'paperless classrooms', where students are provided with computers, iPads, and other electronic reading devices to read and learn from (Giebelhausen, 2015; Shishkovskaya et al., 2015). For instance, as of January 2014, around 17,000 schools across 100 countries were using Blackboard, an electronic learning management system, to distribute reading materials to their students (Corcoran, 2014). As of 2017, the Times Higher Education Reputation Ranking reported that 80% of the world's top academic institutions were using Blackboard to deliver learning materials online. Moreover, iPads have become popular as 1:1 devices in many school classrooms because of their pedagogical value due to their portability, touch screen feature, and affordable hardware and software (Geer et al., 2017).

The Covid-19 pandemic of 2020 has driven many educational, commercial, and social activities online. A recent survey conducted in April 2020 by the Pew Research Center (2020) found that roughly half of the surveyed U.S. adults (53%) said the internet had been essential for them personally during the pandemic (Vogels et al., 2020). However, the pandemic has raised several concerns about the digital divide. For example, individuals without access to technology may be hindered in their ability to complete everyday tasks or schoolwork at home. This has led to concerns that students' learning may be harmed, especially among those from lower-income homes. In the survey, 37% of adults said K-12 schools had a responsibility to provide all students with laptops or tablet computers in order to complete their

work at home. Therefore, it is crucial that current research investigates learning across study media to provide educators, policy-makers, and students with information to help inform their decisions related to the future of learning amid an ongoing pandemic crisis.

According to Alexander and Jetton (2000), to 'get by' in the modern world, there is a requirement for the ability to read and learn from textual material. Moreover, Fox and Alexander (2016) suggest that reading is a lifelong process that enables one to extract meaning from written information in multiple contexts. With textual information increasingly presented online in a variety of formats, there is a need for current research exploring differences between reading on paper and on screen. Of particular importance are investigations into how individuals learn from, and interact with, different types of digital texts compared to print texts.

One way of exploring how readers learn from different types of texts is by assessing reading comprehension, which is the end-product of multiple lower-level and high-level processes that are fast, efficient, interactive, and strategic (Wylie et al., 2018). Lower-level processes include word recognition and (i.e., understanding of things explicitly stated within a text), whereas higher-level processes include updating, inferencing, inhibition, and integration of prior knowledge (i.e., things that go beyond what is explicitly mentioned in a text). These reading comprehension processes are highly important when exploring how individuals learn from texts. Other processes are also very important for learning. Throughout this thesis, the role of prior knowledge, working memory, and navigation, in reading comprehension will be explored. Al-Sulaimi and Al-Shihi's (2018) study examined other relevant factors when assessing reading comprehension across study media, and found that readers' attention, reading speed, reading workload, and reading preference were

important. This introductory chapter will discuss reading comprehension across study media. Subsequent chapters will go into greater detail about other relevant reading processes and how they relate to navigation and learning.

1.1.1 The Paper versus Screen Debate

Given the dominance of digital media in modern life, interacting with screens to read seems inevitable. With schools and universities prioritising technological resources over textbooks, students are reading less on paper and more on electronic devices (Cartelli, 2012; Neumann, 2016). However, is there equivalence in the way readers learn from print and computerised texts? Murphy and colleagues (2003) suggested almost two decades ago that, "the strategies requisite for comprehending traditional printed text are not the same strategies required to comprehend computerised texts" (p. 528). Texts presented on screen now take a range of formats, some of which are part of complex interconnected systems of webpages (described later in this chapter).

An advantage of reading from screens is that it is convenient; electronic texts can be accessed from many devices and are associated with lower costs versus print texts (Hancock et al., 2016). For instance, e-readers are electronic devices that can store and display thousands of books in one handheld device and can connect to the internet, facilitating instant access to an ever-expanding library of texts. However, others have expressed concerns about reading from screens; critics suggest comprehension, engagement, and overall experience is worse when reading on screen versus paper (for example, Herold, 2014; Mangen & Kuiken, 2014; Mangen et al., 2019; Mangen et al., 2013; Noyes et al., 2004; Singer & Alexander, 2017).

This has led some to propose an overall *screen inferiority* effect, in which digital text readers have weaker performance, and metacognitive awareness of their performance, than print text readers (Ackerman & Lauterman, 2012). For example, research exploring students' comprehension of short expository texts (less than 500 words) have found that reading comprehension was better for print than for digital texts (Kerr & Symons, 2006; Verdi et al., 2014). Other researchers have reported no significant differences in the reading comprehension performance of students for print or digital mediums (Akbar et al., 2013; Rockinson-Szapkiw et al., 2013; Young, 2014). Consequently, a debate has arisen regarding the advantages and disadvantages of reading on screen versus paper, with conflicting findings from numerous studies fuelling opponents and proponents of each medium.

Comparison studies of paper versus screen reading help show the differences between media for learning outcomes. A study conducted by Mangen et al. (2013) tested the reading comprehension performance of 72 primary school children reading either a print text or a digital text. They found that students who read on paper performed significantly better than those who read the same texts presented on screen. The researchers suggested that readers may have found it easier to remember what they had read on paper than on screen because paper has 'spatiotemporal markers' which aid memory of where information is located. These markers include the ability to touch the paper, feel its size and weight, and physically turn the pages. For example, print books have physical properties which indicate how long they are; lengthy tomes such as Tolstoy's 'War and Peace' will have a distinct feel from, say, Hargreaves' 'Mr. Men' children's books which are much shorter. The sensation of turning pages and feeling the comparative physical weight of books is not possible on electronic reading devices. Although some e-readers mimic the act of turning a

page (by swiping a finger across the screen), it is argued that this does not aid memory in the same way that turning printed pages does. Therefore, tangible qualities of printed books may facilitate readers' memory of the information they contain. This may explain the results of another study which assessed undergraduate students' learning from five texts presented on either paper or screen (Ackerman & Lauterman, 2012), and found that paper readers performed better than those reading from screen (although, groups performed similarly when their reading time was interrupted).

It is not just learning outcomes that are affected by the use of screens. Researchers are now beginning to identify the relationship between screen time and other outcomes related to mood and behaviour, such as symptoms of depression and anxiety (e.g., Maras et al., 2015), and sleep quality (e.g., Mesquita & Reimão, 2007). For example, Hale and Guan (2015) conducted a systematic review of 67 studies published between 1999 and 2014 that investigated the association between screen time and sleep outcomes among children and adolescents. They found that screen time, especially for computer use, was adversely associated with sleep outcomes including later bedtimes and fewer total hours of sleep. One explanation for these findings is that the blue light of a computer or mobile phone screen has been found to suppress the body's production of melatonin, which can result in reduced sleep duration and disruption of sleep (Wood et al., 2013). This has led most electronic devices to include features such as 'night mode', which turns the colour of the display towards the warmer red end of the light spectrum to help prevent disruptions to sleep and eyestrain when reading. Spending too long reading texts on electronic devices can also cause computer vision syndrome, a temporary condition consisting of symptoms such as fatigue, headaches, and nausea (Barthakur, 2013). Therefore,

reading on screen can have several disadvantages other than those related to comprehension.

1.2 Characteristics of Texts and Readers

Having introduced some of the main issues concerning researchers investigating reading and learning from paper and digital texts, it is important to consider which texts and which readers the present thesis will primarily explore. Given the ubiquity of digital texts, many different types are available to suit multiple reading and learning contexts. The individual differences of readers also determine how well a text will be understood, including their motivation, interest, comprehension ability, and prior knowledge. Furthermore, many ways of measuring reading comprehension have been proposed in the literature. Some of the most common methods of measuring comprehension are discussed below, as well as the implications of having a shallow versus deep understanding of textual information.

1.2.1 Introduction to Hypertext

With the rapidly increasing availability and quantity of online information, workers, students, and general readers have a greater chance of facing new problems in selecting and accessing relevant information (Rouet & Britt, 2011; Rouet et al., 1996). Consequently, it is important to find ways for users to interact with information systems so that they are not overwhelmed by the challenges of finding and organising information online. One format has been proposed as a means of facilitating the interactions between readers and digital text – *hypertext*. Originally coined by Ted Nelson, 'hypertext' refers to non-sequential or non-linear text and is defined as, "a body of written or pictorial material interconnected in a complex way that it could not be conveniently represented on paper" (Nelson, 1987). Since its

creation, educators have proposed that hypertext enables readers to develop rich, highly interconnected knowledge structures necessary to gain a deep level of textual comprehension (Charney, 1987; Fredin, 1997).

Hypertexts allow readers to move from one section of text to another by clicking on 'hyperlinks', which are usually embedded in a text and have identifiable characteristics such as being underlined and a different colour to the rest of the text. This self-determined navigation behaviour has been considered an advantageous feature for comprehension (Jacobson & Spiro, 1995). However, this might cause readers to find it difficult to organise information from different sections in a coherent manner, something which has been negatively associated with deeper levels of comprehension such as integration (see DeStafano & LeFevre, 2007, for a review). This is because readers traditionally rely on conventional cues in a text that signal relationships among topics, such as relative importance or chronology (Britton, 1994).

For example, western print texts typically follow a chronology, with introductory information appearing within the first few left-most pages, and progress from left to right before concluding in the right-most pages. Similarly, in educational textbooks, information related to a particular topic or subject usually appear in close proximity (i.e., pages appear close together). In addition, contents pages found towards the beginning of a text help orient the reader to where information is located, and the order in which it is presented. However, hypertext systems present text non-linearly, and require readers to decide what information to read and in what order. Although the most structured hypertexts often contain 'next' buttons, which help readers navigate the text in a logical order, other hyperlinks embedded in the text may lead to information that is not in order. This may cause

significant disorientation in readers and difficulty in identifying and navigating the text structure. Consequently, readers rely on other text features or on their prior knowledge to form a coherent mental representation of the text (Amadieu et al., 2010; Potelle & Rouet, 2003). As a result, some have proposed that hypertexts should include graphical overviews to convey the text structure by displaying sections, titles, and their relations to help improve readers' comprehension (Salmerón et al., 2009). Indeed, such overviews in print texts have been shown to improve comprehension, especially if the content is difficult and the reader does not possess prior knowledge of the text topic (Lorch & Lorch, 1996; Mayer, 1979).

One of the main ways in which hypertext differs from other types of digital text is that it is non-linear. Traditionally, information in texts is presented chronologically in a format which allows the reader to navigate forwards and backwards through the beginning, middle and end. This is something that has been replicated in digital texts such as scrolling texts, which present the information as a block of text the reader must scroll vertically to access more of the text. One study found that almost 91% of webpages in 2006 included a scroll bar, highlighting the ubiquity of this feature in digital texts (ClickTale, 2006). While scrolling text format does not require the reader to interact with multimedia features such as hyperlinks, it does require the use of features not found in traditional text reading such as a scroll bar. Sanchez and Wiley (2009) examined the effects of user characteristics like working memory ability on learning from digital scrolling texts in students and found those reading scrolling text had weaker learning outcomes than those who read print text. Furthermore, those with low working memory ability were especially disadvantaged when learning from scrolling text. Some explanations the researchers suggested for their results included: the presence of multimedia features in the

scrolling text condition such as a scroll bar scrolling text increased the cognitive load and attentional demands of readers; low working memory readers did not engage in integration processes; and, the lack of page breaks in scrolling text may have resulted in fewer opportunities to consolidate previously read information as part of wrap-up processes important for comprehension.

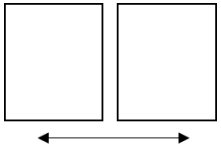
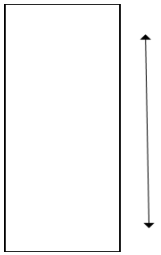
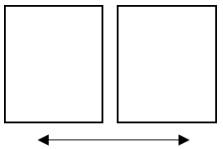
One advantage scrolling text does have over hypertext, however, is that information is still presented linearly, meaning that coherence might not be disrupted as much as if it was presented out of order. Despite this, results of studies showing disadvantages of learning from scrolling text highlight how digital texts other than hypertext may also affect readers' comprehension, with hypermedia features including scrollbars and no page breaks disrupting the cognitive processes required to read and learn from a text. With hypertext having more of these hypermedia features and presenting text non-linearly, this format may place additional demands on the reader and further impair comprehension processes.

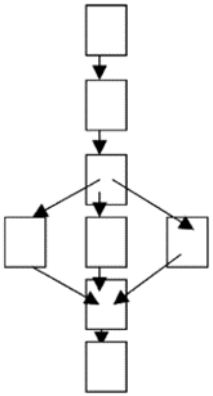
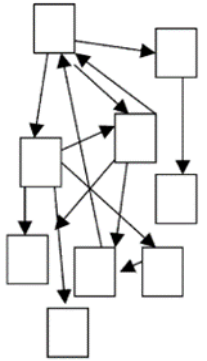
Since the development of hypertext over thirty years ago, the format has established itself as a large part of the digital reading document corpus (Amadieu & Salmerón, 2007). For example, the popular online encyclopaedia Wikipedia uses a hypertext system; each page of information contains an abundance of hyperlinks to take the reader to other pages. Since its conception, many different types of hypertext have been proposed and used in the literature, each with varying amounts of interactivity and features which differ from traditional print text. For example, networked hypertexts are considered more complex than traditional hypertexts, and were created much later. Traditional and structured hypertexts typically contain few hyperlinks and include a 'homepage' or clear starting point for readers to orient their navigation to/from. In contrast, networked hypertexts typically have no clear order,

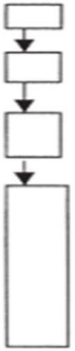
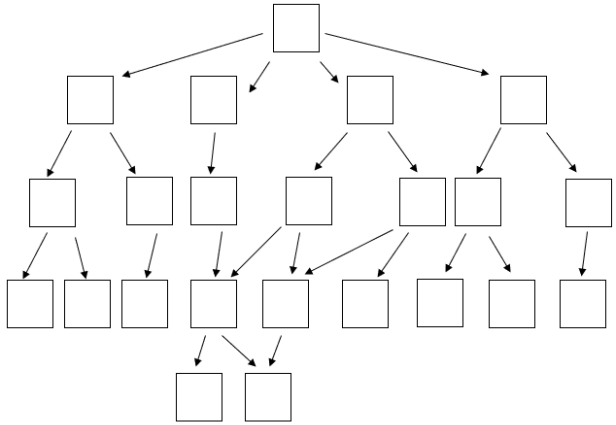
and include multiple pages with numerous hyperlinks which may take the reader to irrelevant or unrelated information. For example, hyperlinks found on individual webpages of Wikipedia may take the reader, following just a few navigation decisions (e.g., 'clicks'), to information mostly unrelated to the original topic. In these networked systems, it is even more challenging for readers to determine the relevance of hyperlinks, how the pages are interrelated, and how to locate and/or relocate read and/or unread information. Table 1.1 includes some brief descriptions of common forms of hypertext and other on-screen texts described in the research literature, some of which are presented throughout the thesis as part of experiments outlined in subsequent empirical chapters (Chapters 4-7). It is important that future research explores how these different types of texts impact on reading comprehension, and assess whether the processes involved in reading these texts are comparable to those involved when reading from print text.

Table 1.1

Descriptions of common text types used in relevant research literature.

Text Type	Description	Overview
Print Text	Text printed out onto paper. All sections presented in chronological order.	
Scrolling Text	Text appears on screen with all sections presented in chronological order. Readers must scroll down the block of text using either mouse wheel or scroll bar. No hyperlinks.	
'Traditional' Hypertext	Text appears on screen as separate pages. Readers must click on a 'next' or 'back to previous page' button to move forwards or backwards throughout the text instead of turning pages as in print text reading.	

Text Type	Description	Overview
Structured Hypertext*	Text presented on screen as individual webpages, with each page being a different section of the text. Readers generally open the webpage on the (chronologically) first section of the text and may navigate to other sections either by clicking on hyperlinks, or a 'next page' button.	
Networked Hypertext*	Text presented on screen as individual webpages, with each page being a section of the text. A page may contain several hyperlinks, taking the reader to a section not necessarily in chronological order.	

Text Type	Description	Overview
Expanding Hypertext*	Text presented on screen as individual pages. Page contains links of key terms that allow the reader to have more detailed information without losing the linear flow of information. A scroll bar allows for referring back to previous information.	
Hierarchical Hypertext*	Text presented on screen as individual pages. Readers move up and down the hierarchy of pages, exploring subordinate and superordinate relationships. In the simple architecture, users cannot navigate laterally. However, in the complex relational architecture, users can navigate laterally to other pages related by subject matter.	

***** Structured and networked hypertext overviews taken from Lee and Tedder (2003); Expanding hypertext overview taken from Lee and Tedder (2005); Simple hierarchical hypertext overview taken from Graff (2005).

1.1.2 Individual Differences of Readers

It is relevant to consider the individual differences of readers when comparing comprehension performance across text media. As previously mentioned, processes other than reading comprehension are important for learning (e.g., attention, memory, reading skill, navigation, etc.), however, this section will focus on reading comprehension because it encompasses many processes that will be discussed throughout this thesis. Factors such as medium experience, prior knowledge, and preference may all contribute to how well textual information is processed, learned, and recalled. These factors will be introduced below, and will be explored in more detail in subsequent chapters of this thesis.

One factor that might affect comprehension of digital texts is how experienced the reader is with the digital format. For children growing up surrounded by technology, one might expect them to have acquired the skills necessary to overcome the additional attention demands of digital reading versus print texts (e.g., searching, navigation, and multitasking) at an earlier stage than adults new to such media. However, Delgado and colleagues' (2018) review showed that screen inferiority appears to be increasing along the years. The review found that print text comprehension remained stable, whereas digital text comprehension declined during the same period. Thus, an individual's mere exposure to technology may not be enough to improve their comprehension of digital texts.

How much information a reader already knows about the subject matter of a text is called prior knowledge. Prior knowledge is sometimes specified in the literature as domain knowledge, which is all the information a person possesses about a particular field of study (Alexander & Jetton, 2000; Lawless & Kulikowich,

2006). Both prior knowledge and domain knowledge have been consistently positively correlated with higher learning outcome scores in reading tasks and are considered to be important for comprehending texts (Alexander, 2003; Amadieu, Tricot, & Mariné, 2010; Kintsch, 1988; Lawless et al., 2007). Numerous studies have found that readers' prior knowledge can help them to orient their attention towards more relevant information, make inferences, and accurately refute false assertions made in a text (Alexander et al., 1994; Kendeou et al., 2014; Lawless et al., 2007; Richter, 2009).

However, results have been more inconsistent for digital texts; some studies have found no relationship between prior knowledge and learning from digital texts, especially for high prior knowledge readers (Chen & Macredie, 2010; Sullivan & Puntambekar, 2015). For example, Sullivan and Puntambekar's (2015) study found no significant relationships between prior knowledge and navigation or learning. They suggested the results reflected the challenges students of all ability levels have when learning from hypertext. This claim is supported by other research findings that students have difficulties understanding conceptual relationships in hypertext (Sullivan et al., 2011). In contrast, others have found that low knowledge readers have increased feelings of disorientation and weaker comprehension when learning from hypertext (Amadieu et al., 2015; Amadieu et al., 2010). Therefore, the conflicting findings in the relevant research literature motivate the need for future investigations into the impact of prior knowledge on navigation and learning across study media.

Some studies investigating the differences between paper and screen learning include a measure of reading preference. Previous research has found that user preference predicts reader satisfaction and the extent to which they engage with a

piece of information (Merga, 2014; Rojeski, 2012). For example, Merga's (2015) review found that very few adolescents choose to read an electronic book over a paper book. In addition, studies included in their review found that there is not enough evidence to suggest that readers generally prefer e-books to paper books (Jeong, 2010; Tveit & Mangen, 2014). A study by Kretzschmar and colleagues (2013) compared reading effort on three different paper and screen texts. Although the screen texts were not found to be more effortful to read from than the paper texts, all participants in their study reported that they preferred reading from paper versus screen. The researchers suggested that this might be reflective of a cultural attitude towards digital reading (e.g., scepticism of its benefits) rather than the process of reading this format requiring more cognitive effort. Furthermore, a recent international study of 10,293 tertiary students found that a large majority reported a preference for print when reading academic materials versus digital texts, especially for long texts (Mizrachi et al., 2018). Moreover, students also reported better focus and retention of information presented in print. Therefore, despite the increase in academic materials presented online, students around the world frequently say they prefer reading and learning from print texts versus digital texts. Importantly, they also report that they remember print material better.

Myrberg and Wiberg's (2015) literature review sought to explain why students prefer to print out electronic textbooks onto paper. They found that readers' habits and attitudes were particularly important in determining which format they choose to engage with. Myrberg and Wiberg (2015) suggested that technological shortcomings of screens, such as the absence of spatial landmarks, might contribute to why many still prefer and choose to read from paper over screen texts. This could explain why readers are increasingly returning to paper books. While Kindle e-book

downloads outsold paper copies on Amazon for the first time in 2011 (see Barron, 2011), sales of physical books increased by 4% in the U.K. between 2016 and 2017 whereas e-book sales reduced by the same percentage (Wood, 2017).

Evidently, there are many ways in which digital media are consumed at present. Technological advancements have resulted in a multitude of electronic devices that can display a range of texts. Furthermore, there is evidence for disadvantages of reading on screen versus paper, with readers consistently reporting a preference for paper texts. Future research should further explore the effect of text media on learning outcomes and reading comprehension. To conclude this section, many individual differences can affect how well a reader comprehends a text. Subsequent chapters will explore in more detail how other factors such as working memory, metacognition, prior knowledge, interest, and mental effort relate to comprehension. These, among other factors, are also important in how students learn from print and digital texts.

1.3 Assessing Comprehension of Texts

The amount of information a reader can extract from a text is generally called *reading comprehension*. Reading comprehension involves multi-layered processes such as decoding of words, extracting meaning from sentences, and drawing inferences (Kintsch, 1998). Comprehension may be assessed by a variety of question types, including multiple-choice, open-ended, and free recall (van den Broek et al., 2009). Performance on these assessments involves a variety of interdependent skills such as word identification, developing ideas from words, and connecting those ideas together to form a coherent mental representation of a text (Kintsch, 2012; Magliano et al., 2007; Perfetti & Adlof, 2012).

It is common for measures of reading comprehension to be categorised as either ‘literal/textual’ (used interchangeably throughout the literature) or ‘inferential/integration’ (Bowyer-Crane & Snowling, 2005; Elleman, 2017). On the one hand, textual comprehension assessments usually require specific details of a text to be recalled, focusing on readers’ memory of information like dates, names, or facts (Hosp & Suchey, 2014). These types of assessment items may take the form of multiple-choice or closed- answer questions not requiring the reader to go beyond what the text explicitly states (Tarchi, 2017).

On the other hand, inferential comprehension assessment items may require inferences based on parts of the text, across parts, or require the integration of prior knowledge (Cain et al., 2004; Clinton & van den Broek, 2012). Inferential items may require the reader to form an opinion or evaluate the reliability of a text and will sometimes be short-answer or essay-based, allowing for the assessment of a deeper understanding of a text. Because of this, measures of inferential understanding are considered more difficult (i.e., requiring the recruitment of greater cognitive resources and mental effort) than textual measures (Basaraba et al., 2013). In agreement with this, previous research has found that the most challenging of reading tasks, like those requiring inferences to be made, result in weaker comprehension for students reading form digital versus print texts (Baron, 2015). Therefore, one might speculate that any differences between media might be found when assessing deeper-level inferential comprehension performance rather than more shallow-level textual comprehension. Therefore, future research may investigate both textual and inferential reading comprehension when assessing differences between study media.

Aside from outcome measures of text comprehension, process measures also help assess how well information is understood when presented on either paper or on screen. For example, reading times and page selection are typically recorded to show how much time an individual takes to read some text across multiple pages. This may include how much time is spent looking at relevant or irrelevant information to the reading goal (e.g., Salmerón & Naumann, 2016). Process measures of digital text comprehension are usually assessed by looking at readers' navigation behaviour, which includes the duration of time spent per page, number of 'clicks', and order in which separate pages of a digital text are accessed Navigation behaviour is typically assessed by log-file analysis, which records information about activity during a reading task (Barab et al., 1997; Hahnel et al., 2016). A subsequent chapter will explore navigation behaviour in more detail, including the characteristics of advantageous navigation styles for good comprehension of a text (see, Chapter 3).

Researchers sometimes ask participants to assess their own learning during a reading task (Ackerman & Goldmsith, 2011; Ackerman & Lauterman, 2012). This may include measuring a prediction of performance (e.g., an overall score prediction), or a judgement of learning (e.g., a self-assessment rating of how well a piece of information has been understood; Koriat et al., 2014). Researchers can then compare these ratings with actual scores to assess how accurate readers are in the monitoring of their own learning. This cognitive process is called metacognitive accuracy (calibration), and will be described in more detail in a subsequent chapter exploring cognitive processes involved in reading (see, Chapter 2).

To conclude this section, there are many ways to assess reading comprehension. Typically, comprehension is tested by outcome measures such as

multiple-choice questionnaires and written tests. However, other process measures such as metacognitive experience, reading strategies, navigation behaviour, and predictions are also informative. Therefore, future research should investigate both outcome and process measures to assess comprehension across study media.

1.4 Comparing Previous Reviews of Comprehension Across Study Media

Multiple reviews of research exploring differences between study media have been conducted. In this section, some of the most relevant and influential reviews will be discussed and compared. It will begin with some of the earliest reviews, before progressing through to the most recent. In doing so, this section will show that earlier reviews reported conflicting findings about the differences between screen and paper learning, whereas later reviews were more conclusive in their summations. It will be shown that questions remain about the impact of several relevant factors including navigation, text type (i.e., scrolling text, hypertext), and individual differences, on comprehension across study media.

An early critical review of empirical literature on differences between reading from paper and screen was carried out by Dillon (1992). The review distinguished between outcome and processes measures when reading. On one hand, outcome measures were defined as variables which assess the end results of a reading task, such as total time taken to read the text, amount of information retrieved, and accuracy of recall. On the other hand, process measures were related to how the reader uses a text, including where the reader looks in the text (i.e., eye movements), and how they 'manipulate' it (i.e., navigation behaviour). Dillon's (1992) review found that there were some disadvantages of reading on screen versus paper. Process measures such as ease of navigation and locating information were

identified as being more difficult on screen than on paper (Richardson et al., 1988). Hypertext was identified as being particularly difficult to navigate (Conklin, 1987). In addition, the outcome measure of reading speed was found to be slower for screen than paper (e.g., Gould & Grischkowsky, 1984), but it was suggested that this might be overcome by ergonomic improvements such as increased display size.

When exploring reading comprehension, Dillon's (1992) review found no differences between study media. The author concluded that the differences between paper and screen reading could not be accounted for by examining any single variable, and that just testing isolated variables such as direct recall or eye movements acted as a barrier to identifying any differences between media. Instead, they suggested that researchers examine several process and outcome measures when testing participants' completion of a range of reading tasks on both paper and screen. A limitation of this review is that it was conducted at a time when the differences between print and digital texts was vast – little ergonomic research had yet been carried out with a view to improving user experience of those reading from screen, and so direct comparisons between the two media were difficult to make. On the one hand, since this review was conducted, much research has been conducted on improving how users interact with digital texts, and has resulted in multiple multimedia features that are designed to facilitate learning and navigation (e.g., screen resolution and brightness). On the other hand, this has led to additional differences between digital and print text reading, which may have increased the differences (e.g., reading speed, navigation behaviour) between digital and print texts. The extent to which study media can be compared will be further discussed throughout this thesis, including the discussion chapter (see, Chapter 8).

Noyes and Garland (2008) conducted a follow-up review of literature exploring paper and screen differences in the 15 years proceeding Dillon's (1992) work. The authors concluded that comparing comprehension across print and digital texts is challenging, with researchers using an array of tasks and measures across mediums. However, they reported that technological developments in the ways computerised texts are presented had resulted in more sophisticated comparative measures since the earlier review and had improved user experience by reducing challenges to digital text reading such as disorientation (Ahuja & Webster, 2001; Amadieu et al., 2009; Otter & Johnson, 2000).

The review differentiated between three types of reading outcomes tasks in the paper and screen comparisons: non-standardised, open-ended tasks (e.g., opinion/judgment short-answer responses); non-standardised, closed tasks (e.g., multiple choice tests); and standardised tasks (e.g., school-administered standardised tests). They found that there were advantages of using computers in assessment, including standardisation of test environment, online scoring (which has faster feedback and greater accuracy), and 'richness of interface' (e.g., dynamic presentation of content and the ability to capture reaction times. Despite this, they highlighted some disadvantages of testing using this medium, including hardware and software problems (time wasted due to freezing or crashing; see, Zandvliet & Farragher, 1997), the computer screen (long reading sessions leading to greater fatigue; see, Ziefle, 1998), and serial presentation (greater difficulty looking through items in order on screen). Although the researchers concluded that much progress had been made since Dillon's (1992) review towards equivalence between paper and screen, particularly in testing, they proposed that more experimental research is

required to understand the differences in the reading processes involved in paper and screen learning.

Two separate meta-analyses focused on the influence of media type on reading outcomes primarily in the K-12 student population (Kingston, 2008; Wang et al., 2007). They examined performance on standardised and non-adaptive tests presented on paper and screen. While Wang and colleagues' (2007) analysis found better reading outcomes for print-based over digital-based testing, Kingston's (2008) meta-analysis revealed a small advantage for digital administration in the academic subjects of English Language Arts, Social Studies, and Mathematics. However, they found that the digital administration of other academic subjects resulted in no consistent or significant effect of media on assessment of reading. The analyses used in these studies were limited as they examined just K-12 students in testing environments and did not explore potential moderators such as text genre (narrative versus expository), reading times, or user experience.

Singer & Alexander (2017) conducted a systematic literature review of studies published from 1992 to 2017. Similar to the conclusions previously reached by Dillon (1992) and Noyes and Garland (2009), they highlighted a lack of clarity in definitions of reading and digital reading in addition to the absence of important information in the reporting of several studies. For example, information such as scoring criteria, characteristics of the reading tasks, individual differences (e.g., working memory, reading abilities), and basic features of the text (e.g. genre, difficulty, length) were often left out. The researchers suggested that inconsistencies in definitions and exclusion of important information might hinder the ability to reach conclusions regarding the effect of print and digital texts on comprehension. Therefore, they aimed to identify how researchers defined and measured

comprehension, and any trends that might have emerged in the 25 years since Dillon's (1992) review.

In their review, they included 36 empirical studies involving both print and digital reading which measured more than just self-report measures and included an outcome measure of comprehension. They also considered several other variables including text genre (expository, narrative, or both), text length, setting (academic versus non-academic), and comprehension. They found that just eight articles defined the concept of reading, either conceptually (speaking broadly about what the nature of the process of reading is; Stern & Shalev, 2013), componentially (describing the elements, skills, or abilities related to reading such as, "understanding words, sentences and paragraphs"; Ali et al., 2013, p. 21), or operationally (related to *how* one reads, such as by forming connections between prior knowledge and new ideas presented in a text; Singer & Alexander, 2017). In addition, it was identified that many studies did not define the concept of reading or what was involved in the reading tasks. Moreover, definitions of what digital reading entailed was also not routinely provided in the reviewed studies.

Singer and Alexander (2017) reported that conclusions were difficult to reach due to the lack of clarity in these definitions across the literature, despite a dramatic increase in the number of publications of empirical studies comparing reading from screens and paper over the last 10 years. They found some support for print texts producing better outcomes versus digital texts (e.g., Singer & Alexander, 2016), although much of the research was inconsistent. Therefore, there is a continuing need for researchers to investigate how factors related to the reader (e.g., working memory ability, prior knowledge, navigation strategy knowledge) and text (e.g., genre, difficulty) relate to paper and screen learning.

A meta-analysis examined research comparing the reading of comparable texts on paper and on digital devices conducted between 2000 to 2017 (Delgado et al., 2018). The investigators attempted to address the conclusions of previous paper versus screen reviews that the effects of medium on comprehension had largely been inconclusive (Kingston, 2008; Noyes & Garland, 2008; Singer & Alexander, 2017; Wang et al., 2007). They suggested that the mixed results may be due to the inclusion of studies using digital texts with sets of features that are not present in print texts such as hyperlinks and other online interactive multimedia features. Furthermore, potential moderating factors were not considered in many of the reviewed studies. For example, Ackerman and Lauterman's (2012) study found media equivalence under no time pressure reading conditions, whereas screen inferiority when reading under greater time pressure. Therefore, Delgado et al.'s (2018) meta-analysis restricted their review to empirical studies making comparisons between print text and linear digital documents without interactive features to improve reliability of measurement.

Their analysis revealed an overall advantage for print text reading with three significant moderators: (1) time frame: the print text advantage increased when time was constrained relative to self-paced reading; (2) text genre: print text advantage increased for informational texts relative to narrative and mixed texts; and (3) publication year: there was an increased advantage for print text reading along the years. They proposed an explanation for why increasing exposure to technology over time has not reduced screen inferiority versus paper: the majority of digital media consists of quick interactions driven by immediate reward (such as the number of 'likes' a post to social media gets) which contributes to a poorer quality of attention (Courage, 2017). Readers using digital devices may find it difficult to

engage in challenging tasks such as reading lengthy informational texts and completing subsequent comprehension tests, because they require sustained attention and do not provide consistent immediate rewards. This effect has been called the '*Shallowing Hypothesis*', a theory which cautions against the rapid introduction and largely undertested impact of digital reading in classrooms (Annisette & LaFreniere, 2017). The results suggest that, despite mixed findings amongst the literature, there is evidence for screen inferiority over paper. The authors concluded that there are some predictable conditions for reading from screen that allow for equivalence with print text – in particular, when comparing linear texts. They suggest that future research should further explore how students learn from informational texts presented on paper and screen and consider factors such as time pressure. The review did not explore different types of on-screen text such as hypertext. Future research could explore how non-linear texts presented on screen can be compared with print texts, and assess reading outcomes including comprehension, preference, and navigation behaviour.

Kong and colleagues (2018) conducted a meta-analysis of 17 studies which primarily focused on a comparison of reading on paper and on screen from the perspective of reading comprehension and reading speed. Their inclusion criteria were studies with clearly defined reading comprehension (test or quiz score) and reading speed (time taken to read texts) measures. Text type (e.g., narrative, informational) and text length were not considered in their analysis. Results of the robust variance estimation (RVE) meta-analysis found that there was an overall advantage of reading on paper than reading on screen for reading comprehension. With regard to reading speed, the analysis showed that there was no difference between mediums. However, greater reading comprehension performance when

reading from paper compared to screen indicates that paper reading may be more efficient than screen reading because there is better performance despite similar time investments. The investigators suggested that the advantages found for paper might be due to readers' experience of reading from this format, i.e., preferring print text reading may have strengthened their reading strategies, leading to better comprehension. A potential limitation of this meta-analysis is that it included both expository and narrative texts, when others have suggested that differences between on paper and screen reading outcomes are more prominent for expository texts only (Delgado et al., 2018; Salmerón et al., 2018; Broek, 2018; Singer & Alexander, 2017). Additionally, the study did not consider potential moderators such as experimental design, working memory, or metacognitive experience, and did not clearly define the types of on-screen text used in the research it reviewed (e.g., linear versus non-linear text).

A recent systematic review and meta-analysis conducted by Clinton (2019) identified 33 studies conducted between 2008 and 2018 that met their inclusion criteria of testing reading comprehension performance, reading time, and calibration from both paper and screen. The study intended to expand upon the work by Kong et al. (2018) by examining the moderators of genre and age, in addition to textual and inferential measures of reading comprehension. Clinton's (2019) review found that digital text reading had a significant negative effect on performance scores compared to reading from paper. Considering the text genre, reading performance for expository texts was weaker in screen texts than in print. However, no differences were found for narrative texts, supporting others' assertions that media effects are more prominent for informational texts (Delgado et al., 2018; Salmerón et al., 2018; Singer & Alexander, 2017). Furthermore, there was a benefit of paper for

both textual and inferential reading comprehension measures. This finding challenges the claim that differences between media in performance might be found only for inferential measures, which are more challenging than literal/textual measures, due to reading from screens being particularly detrimental for challenging reading tasks (Baron, 2015; Basaraba et al., 2013). Reader age was found not to be a significant moderator; both children and adult readers had similar benefits in comprehension performance from paper versus screen texts.

Findings related to process measures of reading revealed that there was no effect of media on reading times. Readers of both paper and screen reported an overconfidence of performance, with screen readers being less calibrated (actual performance subtracted from predicted performance; see Ackerman & Goldsmith, 2011) and more overconfident than paper readers. This poor calibration accuracy effect when reading from screens might be explained by readers thinking that they understand the text better than they do, leading to poorer comprehension (Sidi et al., 2017). Another explanation might be due to a 'mind wandering' effect where readers engage in thoughts unrelated to the reading task, possibly due to a distracting nature of reading from screens, something which has been shown to be negatively associated with reading comprehension performance (Muir & Hawes, 2013; Randall et al., 2014; Unsworth & McMillan, 2013). Clinton (2019)'s review concluded that there is an overall advantage for reading and learning from paper versus screen texts, especially when those texts are expository, and the assessments are both literal and inferential.

One limitation of the conclusions drawn by this review is that they did not consider alternative process measures as an explanation for the results. For instance, reading strategies such as spending more time reading relevant information and

selecting relevant pages have been shown to affect how learners navigate through informational texts (Coiro & Dobler, 2007; Kol, 2000; Salmerón et al., 2015). These strategies can impact the efficiency of navigation, particularly through screen texts, with better navigation positively predicting learning outcomes (Barab et al., 1997; Hahnel et al., 2015; Salmerón & Naumann, 2016; Salmerón et al., 2005). Therefore, research investigating the reading strategies and navigation behaviour of paper and screen readers is needed to help explain the differences between media for reading performance. Additionally, there are many types of on-screen text, including non-linear hypertext. Much research has explored the differences between paper and screen texts when presented in a linear format, whereas few studies have explored the effects of different types of non-linear texts (e.g., types of hypertext) on comprehension. Therefore, a direction of future research could be to compare the reading comprehension of students learning from different types of hypertext with print text comprehension.

1.5 Chapter Summary

The aim of this chapter was to introduce the main areas of interest for research investigating the differences in learning and navigation across study media. It identified that there has been debate about the advantages and disadvantages of digital text learning compared to print text learning. Previous literature reviews have found mixed results about which medium is 'best' for learning, but recent findings suggest there is an overall advantage for reading print texts over digital texts. Of the multiple types of digital texts available in the current corpus of e-learning materials, hypertexts appear frequently. Studies have found many disadvantages of reading from this format over print texts, and there is evidence that hypertext impacts comprehension.

Gaps in knowledge about the comparative impact of different types of hypertext exist, and there is a need for research into how hypertext impacts navigation and comprehension, and how this might be improved. Most of the relevant research has assessed learning by looking at the lower and higher-order processes that comprise reading comprehension. In particular, word recognition, updating, inferencing, inhibition, and integration of prior knowledge are all important factors in determining comprehension performance. Other factors are also very important when investigating differences across study media, such as, attention, working memory, metacognition, as well as readers' preferences, mental effort, and interest. These other factors will be explored in more detail in the following chapter.

Chapter 2: Cognitive Processes for Reading

This chapter will explore the key cognitive processes involved in print and digital text comprehension. It will identify that the ability to process verbal, visual, and spatial information, monitor one's own learning, and manage attention is vital for understanding textual information. Therefore, a selection of relevant models of reading comprehension, working memory, and metacognition will be described. It will also describe some of the most influential theories of reading comprehension and discuss how they can be applied to learning in digital contexts. For instance, the Construction-Integration (C-I) model shows the importance of building coherent mental representations for the understanding of a text, describing how text structure, the ability to extract meaning, and integrate prior knowledge are vital for comprehension. Alternatively, the Landscape model proposes how levels of activation fluctuate during reading cycles and describes how readers' standards of coherence influence how much information is retrieved and whether prior knowledge is integrated. Both of these models assume that readers engage in functional and coherence-driven processes to understand texts, which is important for the comprehension of both print and digital texts.

As briefly introduced in Chapter 1, comprehension is the complex multi-dimensional process of extracting meaning from information. While comprehension is necessary for a range of everyday activities including learning, problem solving, and decision making, much of the research investigating comprehension has been conducted in the context of text and discourse (Barzillai et al., 2018; Britt et al., 2017; Graesser et al, 1997; Millis et al., 2006). Reading comprehension involves processing the phonological, orthographic, and semantic representations of individual words to understand the meaning of individual words, sentences, and the

text as a whole (van den Broek et al., 2014). If the reader is to fully comprehend a text, it has been suggested that they must engage in several passive and strategic inferential processes to help build a coherent mental representation of the information (Kintsch, 1988). Passive inferential processes are thought to be automatic and occur quickly with little mental effort. This includes letter and word recognition, text length, and spacing between words and sentences. In contrast, strategic inferential processes are more complex and place additional demands on readers' attentional and working memory resources (van den Broek et al., 2005). Examples include integrating new information with prior knowledge, assessing relevancy, and creating semantic links between multiple sections.

Engaging in both passive and strategic inferential processes is necessary for the comprehension of texts. However, each set of processes require different levels of cognitive effort to perform. Thus, researchers often distinguish between a variety of lower and higher-level processes when attempting to understand the cognitive processes that are involved during reading comprehension (Balota et al., 1990; Clinton & van den Broek, 2012; Elleman, 2017; McNamara & Magliano, 2009).

Lower levels of processing in reading comprehension refers to the basic identification and understanding of words and ideas explicitly expressed within a text. Whether the reader has understood this information is then often assessed through textual comprehension items which require the recall of specific details of the text such as names or dates (e.g., Hosp & Suchey, 2014). In contrast, higher-level processes such as inferential and deductive reasoning, critical analysis, and reflection, are cognitively more time-consuming and are essential for what has been called 'deep reading' (Wolf & Barzillai, 2009). Deep reading is often assessed through inferential comprehension test questions, which may require the reader to

form an opinion or compare multiple ideas presented throughout a text (e.g., Amadieu, Lemarié, & Tricot, 2017; Salmerón et al., 2017).

Annisette & LaFreniere (2017) argue that the current digital culture emphasises immediacy, with many online behaviours consisting of quick interactions and immediate rewards (e.g., 'likes' on social media). The authors suggest that as people increasingly use digital media for shallow interactions, they will find challenging tasks more difficult, as they require sustained attention and deeper immersion - something the authors call the 'Shallowing Hypothesis'. Consequently, modern readers might have fewer opportunities to engage in higher-level processing due to digital media facilitating less cognitively demanding interactions. This hypothesis is supported by others' findings which show a negative correlation between frequency of digital media use and text comprehension (Duncan et al., 2015; Pfost et al., 2013). Moreover, Delgado and colleagues (2018) conducted a meta-analysis of research comparing print and digital texts between the years 2000 to 2017, and found an increasing advantage for paper-based texts during this period.

In addition, a phone manufacturer's recent survey of more than 2000 smartphone users of all ages found that 16 to 24-year-olds were more likely to lose their temper due to slow download speeds than older users, a phenomenon called the 'Load Rage' effect (Petter, 2019). The survey also found that 75% of this age group reported download speeds and internet connectivity as being the most frustrating element of their lives, a reflection of how important the immediacy of access to information is to modern digital users. Therefore, it is vital that the cognitive processes involved in reading from digital texts is understood in order to help prevent a generation of digital natives who are unable to engage with information on a deeper level.

2.1 Theories of Reading Comprehension

While there have been several models of reading comprehension proposed in the literature (for a review see McNamara & Magliano, 2009), some approaches are used more frequently than others to interpret the findings of the research most relevant to the aims of this thesis. Therefore, some of the most relevant perspectives will be described briefly, including some examples of how they can be applied to individuals' behaviours during print and digital text reading.

2.1.1 Construction-Integration Model

Kintsch's (1998) seminal general processing framework for cognition, the Construction-Integration (C-I) model, is one of the most widely applied models to reading comprehension. According to the C-I model, comprehension of a text is the result of a task-driven construction process in which readers form a mental representation (Kintsch, 1988; Kintsch & van Dijk, 1978). Construction refers to the activation of information contained within the text and includes the initial activation of knowledge (both relevant and irrelevant). Integration refers to the spreading of activation, where relevant prior knowledge is integrated with new information contained within a text. The model distinguishes between the three mental representations that a reader forms: a) the surface structure (individual words and syntactic structure), b) propositional text base (underlying meaning of the information explicitly stated within the text), and c) the situation model (inferences about the text beyond what is explicitly mentioned). The C-I model considers many factors to be contributory to text comprehension but assumes that prior knowledge, inferencing, and coherence are among the most important (Rouet & Le Bigot, 2007). When a reader engages with each of these mental representations (with the

propositional text base and situation model being the most important for learning), the reader achieves good comprehension of a text.

While this construction process is considered similar when reading linear texts on paper and screen, the non-linear features of hypertext imposes further demands on readers regarding their *selection* of what text to read as well as the decision-making required at each hyperlink when navigating through the pages (Coiro et al., 2011; Naumann et al., 2008; Salmerón et al., 2005). When reading linear texts, readers are better able to consider the information in its entirety rather than in segments of information. This is because readers can easily navigate to all sections of a text (beginning, middle, and end) when it follows a logical and consistent order. However, the presence of hyperlinks in non-linear texts such as hypertext disrupts readers' ongoing cognitive processes of monitoring and updating because text is segmented and may not follow a chronology. This can result in disruption to each of the mental representations described in the C-I model.

For example, when readers encounter a hyperlink they can either choose to click it immediately or temporarily ignore and return to it later. On one hand, if they click it immediately, which may be before they have even finished reading the sentence in which it is embedded, they risk disrupting the mental representation of surface text structure. This is because the hyperlink might not take the reader to relevant or chronological information. On the other hand, if the reader ignores the hyperlink, then they must remember its location in relation to the rest of the text to return to it later. This requires visual and spatial information to be held in short-term memory while also continuing to read and process new information. According to DeStefano and LeFevre (2007), this can build significant cognitive load and disrupt working memory processes (this process model of hypertext reading will be

described in more detail later in this chapter). Since any one page of hypertext may contain several hyperlinks, it is easy to see how cognitive resources which might otherwise be used for understanding the meaning of the information (necessary for building a representation of the propositional text base) and making inferences based on prior knowledge (necessary for building a situation model), might be used for remembering the location of links.

Therefore, hypertext places additional processing demands on the reader not found in traditional print text reading. The non-linearity of this format in addition to interaction with hyperlinks means that there is a less coherent text structure and readers may be overburdened, resulting in reduced comprehension. Processes related to readers' ability to integrate relevant prior knowledge and make inferences about the text as a whole are important because, according to the C-I model, when the reader is unable to build these mental representations, comprehension suffers. Considering how the C-I model can be used for future research, researchers should continue to explore how individuals build a mental representation when navigating through hypertext by recording their navigation behaviour and assessing individual reading strategies. In addition, research should investigate whether hypertext impacts readers' ability to integrate prior knowledge to develop a deep comprehension of the text. This may help to elucidate the decision-making process a reader engages in when encountering hyperlinks and features unique to the hypertext format.

2.1.2 The Landscape Model

One of the aims of the C-I model was to describe how readers activate concepts represented by a text, and how they create relations between these concepts

to form a series of mental representations necessary for comprehension (Kintsch, 1998; Kintsch & van Dijk, 1978). The model proposes that reading consists of multiple cycles consisting of each new sentence or concept. At each new reading cycle there are four potential sources of activation: the text currently being processed, information about the preceding cycle, reactivation of concepts processed in earlier cycles, and the access and activation of prior knowledge. Since an individual's attentional resources allow for only a limited number of concepts and relations to be processed at any one time, text elements fluctuate in activation according to sources of activation during reading. Thus, Van den Broek and colleagues (1999) proposed The Landscape model, which aimed to further describe the mechanisms involved in these fluctuating activations by considering how concepts are retained or removed from the focus of attention and working memory during reading cycles.

Similar to the C-I model, The Landscape model assumes there are four sources of activation. However, it focuses on two types of mechanisms involved in the reactivation of concepts processed in earlier reading cycles, and the access and activation of prior knowledge in particular. The first mechanism is 'cohort activation', a passive process involving relating multiple concepts to each other according to how frequently they are activated in working memory. A cohort is a series of interconnected ideas which are useful for helping to build a reader's mental representation of a text. The model suggests that when one concept within a cohort is activated in working memory, then all other concepts associated with that cohort are also activated. This can be useful for quickly making inferences about individual concepts based on knowledge acquired about similar concepts. In print reading of expository texts (e.g., textbooks), information typically follows an expected

chronology with similar concepts appearing close to each other. This can help the reader to identify the location of related concepts. If these related concepts appear far apart from each other (e.g., the first few pages and the last few pages), then the reader can easily turn pages forwards or backwards if they want to reread the related information. This may support the formation and activation of cohorts according to the reader's coherent mental representation of the text as a whole.

The second mechanism is 'coherence-based retrieval'. The assumption underlying this mechanism is that readers set their own standards of coherence which determine how often, and how much, activation of concepts processed during preceding reading cycles and access of prior knowledge occur. For instance, if a reader adopts very low standards of coherence (which may have been influenced by reading goal, motivation, or fatigue) then they may decide that adequate coherence is attained after minimal reactivation or retrieval of prior knowledge has taken place. In this situation, the reader may be content with a shallower level of text comprehension. This may be sufficient if the reading goal requires them to understand basic textual information, but not if the goal requires the reader to engage in deep comprehension processes such as inferring and integrating. Deep comprehension is more likely to be attained when the reader adopts high standards of coherence. In these conditions reading may be slower and involve frequently integrating prior knowledge to help understand the text. In addition, the reader may maintain and update their mental representation of the text by connecting ideas throughout and retrieving previously read information from memory.

The Landscape model can be applied to digital reading contexts. For example, as readers navigate through hypertext they process information across multiple sections. Relating concepts to each other can be more difficult to do in this

context because readers may frequently come across irrelevant or non-chronological information, resulting in fewer opportunities to build and activate cohorts. Even if all of the information is relevant, working memory resources may become overburdened by hyperlinks, with the result that the reader's ability to make connections between part of the text is inhibited. For example, without a coherent text structure readers may not be able to relocate previously read information; readers cannot simply turn a page forwards or backwards through hypertext. Instead, they must navigate through several hyperlinks. Without a clear concept of the beginning, middle, and end of a text, it may be more difficult for readers to relate concepts to each other to form a coherent mental representation of the text. Similarly, readers' standards of coherence may be difficult to attain when reading hypertexts, especially if they are high. For example, the reading goal may require the reader to answer integration questions on a test. Therefore, the reader would have to engage in deep comprehension processes including integrating prior knowledge, making connections between parts of the text, and accessing previously read information from memory.

However, the discontinuity of reading through hypertext and the additional processing demands of engaging with hyperlinks (described in more detail later in this chapter) may result in difficulties building deep comprehension and meeting higher standards of coherence. If hypertext disrupts the reader's ability to form a coherent mental representation of the text then their ability to engage in deep comprehension processes could be affected. Therefore, future research might investigate both shallow and deep comprehension when reading print text versus hypertext.

2.1.3 Other Relevant Models of Reading Comprehension

While the C-I and Landscape models are the most widely applied in the relevant research literature, other influential models of reading comprehension have also been proposed to show how readers process texts. Firstly, the Simple View of Reading (SVR) was developed to show how skilled reading requires a combination of both bottom-up (e.g., word recognition and decoding) and top-down (e.g., language comprehension) processes (Gough & Tumner, 1986). It was developed in response to arguments which debated whether the ability to decode is at the core of reading ability, or whether it may impede the acquisition of literacy. The original SVR model was used to describe types of reading disability, but a later longitudinal study of bilingual children supported the model's primary prediction that a combination of decoding and language comprehension would explain variation in reading comprehension ability (Hoover & Gough, 1990). While this model is useful for demonstrating how reading is a complex process requiring several bottom-up and top-down processes, it is more difficult to relate to digital reading contexts as it does not explore the importance of coherence or mental representations and how non-linear texts might impact comprehension.

Another alternative model of reading comprehension is the Capacity Constrained Reader (CC-R) model (Just & Carpenter, 1980; Just & Carpenter; 1992; Just et al., 1996). This model focuses on lower-level processes such as word recognition and suggests that individual differences in working memory capacities can have an impact on comprehension. It proposes that factors such as syntactic complexity, memory load, and time constraints increase demands placed on working memory. If the capacity of the limited stores of working memory overburdened, then comprehension of the text falls. This model is useful as a description of how

individual differences of readers (e.g., working memory ability) might impact lower levels of comprehension. However, the modern reader engages with many different types of digital text which place varying demands on working memory capacity. The CC-R model does not account for the impact non-linear texts might have on working memory capacity and comprehension.

2.1.4 Models of Online Reading Comprehension

A central issue for researchers investigating the relation between reading processes involved in print and screen interactions has been whether traditional models of comprehension can be applied to the assessment of both mediums. Multiple theoretical perspectives of online reading comprehension have emerged. For example, the Rand Reading Study Group's (RRSG, 2002) report summarises the perspective that reading comprehension is an active, constructive, and meaning-making process in which the reader, the text, and the reading activity are particularly important (Alexander & Jetton, 2000; Kintsch & Kintsch, 2005; Pearson & Dole, 1987). According to Alexander and Fox (2004), the emergence of a greater range of texts (i.e., online texts) introduces additional dimensions to the set of cognitive reading strategies that are usually involved in print reading (e.g., integrating prior knowledge, self-regulating learning, and drawing connections between text parts).

Alternatively, proponents of the New Literacies framework suggest that there are a different set of skills required for reading on the internet than for reading printed texts (Lankshear & Knobel, 2003; Leu et al., 2004; Leu et al., 2005). This perspective argues that the emergence of new technologies means that readers must develop and utilise new comprehension skills and strategies to successfully navigate and learn in new reading contexts. For example, skills related to locating,

evaluating, and synthesising information online have been found to be independent to offline reading skills (Afflerbatch & Cho, 2009; Coiro et al., 2008; Coiro & Dobler, 2007).

A third perspective is the cognitive flexibility view (Spiro et al., 1991). This theory suggests that readers apply what they know about reading print texts when adapting to new and frequently changing online reading contexts. When considering this perspective in relation to hypertext reading, hypertexts may be advantageous for learning, because the reader plays an active role in the reading process and adapts their reading strategies to fit more complex reading situations. The theory suggests that hypertexts may increase opportunities (more than in print reading) for readers to use their existing knowledge in a flexible way to improve comprehension (Spiro et al., 2012).

To conclude this section, traditional models of reading comprehension seek to explain the processes involved in reading and how readers extract information from texts. The C-I model assumes there are different levels of comprehension; the reader forms surface, text base, and situational mental representations that are determined by several passive and strategic processes. Similar to the C-I model, the Landscape model assumes there are sources of activation which occur both automatically and strategically. However, the latter assumes that there are different amounts of activation for these sources during any reading cycle. It also describes specific mechanisms involved when forming a mental representation of a text by proposing a 'landscape' of fluctuating activations.

While online-specific reading comprehension models have also been proposed, aspects of traditional reading perspectives can be applied to digital reading

contexts. For example, digital text readers attempt to form a cohesive mental representation of structure, make inferences based on prior knowledge, and rely on several automatic and passive processes, as do print text readers. In addition, traditional reading models may help explain why hypertext readers are particularly disadvantaged versus print text readers when forming deep comprehension. Inferencing and integration processes are vital for forming a cohesive mental representation of a text, something which is disrupted by the discontinuity of hypertext. Other models of reading comprehension such as the SVR and CC-reader explore core aspects of reading but, for the purposes of this thesis, the C-I and Landscape models are judged to be the most complete and the most relevant. Therefore, considerations of the roles of attention, working memory, and metacognition in the following sections of this chapter will draw upon these models to explore the differences between print and digital text comprehension.

2.2 The Role of Attention and Working Memory

Having described some of the most relevant models of reading comprehension, it is useful to explore the role of attention and working memory in more detail, as these cognitive processes are fundamental to reading. Throughout this section, the importance of attention and working memory for reading in print and digital contexts will be described.

2.2.1 Attention and Working Memory in Print Text Comprehension

While it might appear as though we can divert our gaze to smoothly scan across our visual perceptual field, our eyes are in fact constantly engaged in alternating movements of both short and rapid movements called saccades, and fixation periods (Reichle et al., 2003). The speed at which the eyes move during

saccades creates the effect of masking, which means that only information before and after the movement is perceived. For instance, Rayner (2009) found that the average fixation time during reading is between 225-250 milliseconds, and that an average saccade length is between seven to nine letter spaces (taking around 20-50 milliseconds to perform). Vision has been found to be supressed during a saccade, something which is necessary to reduce a blurring effect occurring when diverting gaze between objects. As a result, new information is acquired only during fixation periods (Matin, 1974). The number of orthographic elements (e.g., letters, syllables) that can be processed during a single fixation is called perceptual span, or visual attention span (Bosse et al., 2007; Rayner, 1998).

An early paper by Huey (1908) mentioned a 'reading range', a limited spatial area in which readers process visual information. This later was more clearly defined as perceptual span, the limited spatial region from which useful visual information is obtained (Rayner et al., 2010). Visual span, on the other hand, is the distance on either side of a fixation point where letters arranged horizontally can be reliably recognised (Legge et al., 2007; O'Regan, 1990). Thus, it can be seen how attention is pivotal in the process of reading. Firstly, individuals must orient their attention towards visual textual information, then sustain their attention, while also supressing the amount of external (non-textual) stimuli being processed. This has led some to claim that effective learning and memory can only take place if the individual has acquired a sufficient level of sustained attention (Broadbent, 1958; Engle, 2018; Rayner, 2009).

Working memory, a concept which some have described as a 'mental workspace', is the set of cognitive resources that individuals use to encode, activate, store, and manipulate information while engaged in cognitive tasks (Baddeley,

2003). Miyake and Shah's (1999) review described several models of working memory proposed in the literature (e.g., Cowan's Embedded Processes Model, 1999; Paivio's dual-coding theory, 1991), with each one addressing theoretical issues related to its mechanisms and representations, how it is controlled and regulated, and its relation to long-term memory. However, the working memory model of Baddeley (Baddeley, 1986; 2003; 2007; Baddeley & Hitch, 1974; Baddeley & Logie, 1999) is the most widely applied within the relevant reading comprehension literature. According to this model, working memory consists of four main components: the central executive, the phonological loop, the visuospatial sketchpad, and the episodic buffer (Baddeley, 2000).

Firstly, the central executive manages resources and allocates attention, acting as a control system for the other subsystems. It updates and regulates the content of working memory, and is associated with the functions of inhibition, set-shifting, and cognitive flexibility (Miyake et al., 2000). Studies exploring the relationship between the role of the central executive for reading comprehension in children have found that inhibition, information updating, and cognitive flexibility are associated both directly (e.g., multiple-choice comprehension tests) and indirectly (e.g., through listening span performance) with reading comprehension performance (Cantin et al., 2016; Iglesias-Sarmiento et al., 2015; Nouwens et al., 2016). These functions are important in the context of reading because readers must inhibit the processing of irrelevant information, integrate prior knowledge, and update and maintain a mental representation based on information previously read and currently being read. The activation of these processes is controlled by the central executive, demonstrating the importance of this subsystem for reading and comprehension (Baadte & Dutke, 2013).

Secondly, the phonological loop processes auditory information, including both spoken and written words. Nouwens et al. (2017) explored the role of phonological (digit span) and semantic (conceptual span) storage in the reading comprehension performance of 123 children. They administered multiple-choice comprehension tests which assessed both explicit and implicit information mentioned in an expository text. They found that both phonological and semantic storage is highly involved children's reading comprehension, demonstrating the importance of the phonological loop of working memory for understanding text.

Thirdly, the visuospatial sketchpad is subdivided into two functions: processing the visual characteristics of objects (e.g., size, colour), and spatial information (e.g., movements, where objects are located in relation to other objects). The visuospatial sketchpad allows visual input to be processed in visuospatial working memory, such as reversing the sequence of objects or manipulating images (Dehn, 2011). Visuospatial working memory has been found to be positively related to reading comprehension in studies investigating factors underlying memory performance in children and adults (Bayliss et al., 2003; Bayliss et al., 2005). For example, Pham and Hasson (2014) explored the relation between verbal and visuospatial working memory and reading ability in children. Based on their findings, they concluded that both verbal and visuospatial working memory play a significant role in reading comprehension. Lastly, the episodic buffer is a temporary store which integrates information from the phonological loop and visuospatial sketchpad with each other and with prior knowledge.

Daneman and Carpenter's (1980) reading span task is one of the most widely used measures of working memory capacity. The researchers identified that traditional short-term memory tasks (e.g., word and digit span tasks) imposed

storage demands by requiring participants to passively repeat back a string of random words. However, they noted that a task involving simultaneous processing *and* storage demands would be better at predicting performance on complex cognitive tasks, such as reading comprehension. Therefore, they created a verbal working memory span task which included a stronger language processing component. The verbal span task involved participants reading progressively longer sets of sentences out loud (processing component) while trying to remember the final word of each sentence in each set for later recall (storage component).

Their studies revealed that scores on the reading span measure were significantly correlated with measures of reading comprehension, demonstrating that individual differences in working memory capacity are related to learning. Recent reviews have identified that research frequently used working memory capacity to link working memory to comprehension performance (Engle, 2018; van den Broek et al., 2016). In addition, there has been extensive research showing the significant relationship between working memory capacity and multiple learning outcomes, particularly in the domain of reading (e.g., Lee & Tedder, 2003; 2004; Swanson & Alloway, 2012; Swanson & Jerman, 2007). Early working memory literature shows that individuals have different working memory capacities; high working memory capacity participants have been shown to remember more information than low capacity participants (Baddeley, 1986; Daneman and Carpenter 1980; Lee-Sammons & Whitney, 1991).

Key components of traditional models of reading comprehension (e.g., word recognition, inferencing, activation of prior knowledge), all require the activation of working memory. For example, the C-I model suggests that as readers progress through a text, several lower and higher order processes are involved in building a

coherent mental representation of the text. According to this view, an important mental representation for building a deep comprehension of a text is the situational model, which relates to the processes of inferring and activation of related knowledge. Readers decide about the extent to which any related knowledge is integrated, enabling them to make inferences about the text beyond what is mentioned explicitly. Working memory is responsible for integrating this knowledge, and is carried out primarily by the limited store of the central executive. If processing demands are high, then the limited working memory stores can quickly become overburdened and comprehension compromised. The CC-R model also suggests that if the capacity of the limited stores of working memory are exceeded, then comprehension of a text declines. Therefore, working memory processes are central to the comprehension of textual information. However, when multiple lower and higher order cognitive processes are activated simultaneously, additional demands are placed on working memory's limited-capacity stores (Logic et al., 1990).

How the cognitive demands of reading and learning tasks can result in these stores becoming overburdened, resulting in inhibited comprehension performance, is in part explained by cognitive load theory (Chandler & Sweller, 1991). Cognitive load is a construct with three measurable dimensions: cognitive load, mental effort, and performance (Kirschner, 2002; Sweller et al., 1990; Sweller et al., 1998). A fundamental assumption of cognitive load theory is that working memory capacity is limited, and that only a limited amount of information can be simultaneously processed before cognitive overload leads to inhibited learning (Baddeley & Logie, 1999; Swanson & Alloway, 2012). According to this theory, there are three categories of cognitive load on working memory during learning tasks: intrinsic

cognitive load, extraneous cognitive load, and germane cognitive load (Paas et al., 2004; Sweller, 2011).

Firstly, intrinsic cognitive load refers to the inherent difficulty and complexity of a learning task (e.g., content found in informational texts that is difficult to learn). Intrinsic cognitive load also relates to prior knowledge because a task will be less challenging if one has greater experience completing a similar task. Secondly, Extraneous cognitive load concerns the instructional content of a task and how the learning material is presented. For example, poorly designed instructional materials might result in readers having navigational or searching issues. A learner might have to spend a portion of their reading time working out how to navigate a text's layout rather than reading the information. These behaviours do not directly contribute to learning, but do require cognitive resources to perform. However, in some cases difficult-to-read materials lead to better performance than easy-to-read materials because of a subjective feeling of task difficulty which results in a deeper learning approach – a phenomenon called the disfluency effect (Alter et al., 2007; Bjork, 1994; Seufert et al., 2017). Lastly, germane cognitive load refers to the load imposed on working memory by learning, such as relating prior knowledge in long-term memory to new information. It has been suggested that appropriate instructional design should try to limit extraneous cognitive load and promote germane cognitive load (Chen & Lin, 2016; Sweller et al., 1998).

2.2.2 Attention and Working Memory in Digital Text Comprehension

Reading comprehension requires active attentional processes (such as orienting and sustained attention) to facilitate the successful processing of text in working memory (Wylie et al., 2018). However, the unique features of digital

reading could potentially impact these processes, resulting in reduced comprehension performance. Digital reading refers to engagement with electronic devices which display text, such as PCs, tablets, and e-readers. Some argue that technology becoming a greater part of our lives is related to a poorer quality of attention (e.g., Courage, 2017), while others suggest that the emphasis on immediate rewards in digital media may result in difficulties engaging in more challenging tasks like deep learning and inference making (Annisette & Lafreniere, 2017). Furthermore, it has been proposed that readers of digital texts engage more in scanning and skimming rather than deeper engagement necessary for greater comprehension (Liu, 2005; 2012).

Reading on digital devices which can connect to the internet may contain a myriad of distracting stimuli such as adverts, window pop-ups, and moving images. These may contribute to inhibiting the kind of focused, sustained attention required to efficiently comprehend target textual information (Baron, 2017; Thain, 2018). For example, Eastin et al. (2006) found that elementary-age students were less likely to recall information from a digital source when the text was accompanied by several pictures and animations. A more recent study investigated the course e-textbook experiences of preservice teachers (Dobler, 2015). Participants noted challenges related to distractions of using e-textbooks including eyestrain and a feeling of being overwhelmed by the quantity of available information, resulting in difficulties regarding the selection of material to read.

Improvements in technology have meant that computerised texts can now appear on small screens such as mobile phones or handheld e-readers. One way in which this could also impact readers' attention is through visual crowding; a phenomenon whereby objects such letters appearing in a clutter can result in

recognition difficulties, particularly in struggling readers (Martelli et al., 2009; Schneps et al., 2010). For example, Petrov and Meleshkevich (2011) identified a link between visual crowding and the allocation of spatial attention. However, one unique feature of digital texts is that they can be presented on computerised devices which allow for the customisation of multiple features of texts, such as page brightness, text window size/shape, and the size, spacing, and type of font (Dalton & Proctor, 2008; Dyson, 2004; Walker et al., 2018). While print texts are usually presented on a uniform set of standardised page sizes, font sizes, and letter-spacing conventions, some research has shown how digital text format modifications such as increased letter-spacing can facilitate reading comprehension by reducing the effect of visual crowding, especially for struggling readers (Schneps et al., 2013b; Zorzi et al., 2012). Therefore, while digital texts may present some difficulties for the allocation of attention, technological improvements allow for customisation which may help reduce these effects.

While most print texts contain a limited number of features, the variety of digital text formats means that there are many ways in which text can be presented, and multiple features which require attentional resources. Many computerised texts are presented in a scrolling format, where text is presented in a continuous block, accessed by scrolling down a page. However, hypertext contains additional features which can impact attention. For instance, the inclusion of hyperlinks means that any one section of text may contain several blue, underlined words (Jonassen & Wang, 1990).

One eye-tracking study found that the presence of a single coloured word within a written sentence reduced the likelihood that the word is skipped (Fitzsimmons, 2017). In addition, gaze fixation times revealed that readers attended

more to low frequency words containing a hyperlink. The researcher suggested that these findings could be due to readers placing greater importance on hyperlinked words, regardless of whether they are relevant to the reading goal. Moreover, incongruence between the prior content and the hyperlinked word may have resulted in additional attentional resources being required to assess the salience of the information. Fitzsimmons' (2017) conclusions may also explain the results of other studies that have found students are sometimes unable to evaluate whether links found on the Web will be useful or distracting (Kamil & Lane, 1998). For instance, Salmerón and colleagues (2018) found that young readers find it difficult to funnel out irrelevant information and focus on their reading goals, resulting in weaker comprehension performance. Such cognitive processes may occur many times when reading hypertext, as hyperlinks can appear many times across multiple sections.

Working memory plays an important role in digital text reading, as it does in print text reading. In print text, readers are required to primarily make forward and backwards decisions to navigate to previously read, or unread information. However, as readers progress through hypertext, they must remember many navigational steps, as well as the content of multiple sections. This led DeStefano and LeFevre (2007) to propose a process model of hypertext reading which aimed to describe the cognitive processes involved during hypertext reading (Figure 2.1).

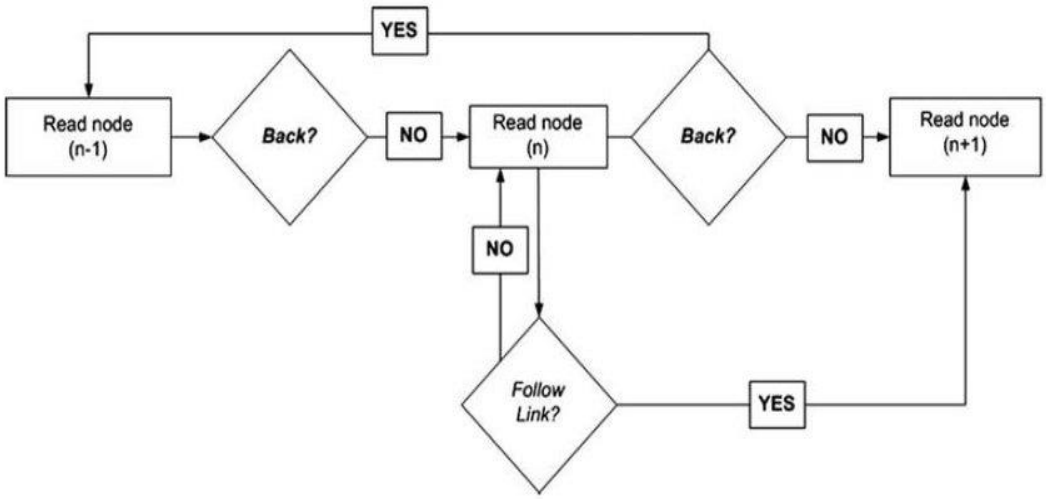


Figure 2.1. Process model of hypertext reading (taken from DeStefano & LeFevre, 2007).

The model shows how, at every instance of a hyperlink, readers decide whether to click the link immediately or return to it later. If they decide to follow the link, then they can either continue on through the text from this new location, or they can navigate back. If they decide not to follow the link, then they can continue reading but must remember the location of the hyperlink if they wish to return to it. These additional cognitive demands of decision-making and visual processing are unique to hypertexts, and the authors of the model suggest that this can result in impaired reading comprehension performance. Theories of reading comprehension can be drawn upon to help explain why this might occur. For instance, the C-I model suggests deep comprehension of a text occurs when readers build coherent mental representations by inferring and integrating prior knowledge. If the limited stores of working memory are overburdened by the additional cognitive demands of hyperlinks (e.g., inhibiting immediate interactions, recalling locations, assessing relevancy), then the ability to make inferences about the text based on prior knowledge may be inhibited. DeStefano and LeFevre's (2007) study found that

readers with low working memory ability and low prior domain knowledge were particularly disadvantaged when reading hypertext. This may be because consistently engaging in additional decision-making processes while reading hypertext disrupted the readers' ability to form a coherent mental representation of the text by increasing cognitive load, resulting in weaker comprehension performance.

Anmarkrud et al.'s (2019) recent review of research investigating the relationship between multimedia learning and working memory (using cognitive load as a major theoretical framework) showed that reduced levels of cognitive load resulted in improved multimedia learning outcomes. In particular, the researchers highlighted how good instructional design for multimedia learning tasks is particularly important for reducing cognitive load. However, they also noted that some studies included in their review lacked a clear conceptualisation or measurement of working memory, and that there were inconsistent findings regarding the relationship between cognitive load and multimedia learning.

Individual differences in working memory capacity can also affect comprehension of hypertext. When working memory capacity is low, cognitive resources required for processing new textual information can quickly become overburdened, inhibiting performance and the ability to connect ideas (Nouwens et al., 2017). A similar conclusion was also reached in an early study by Jonassen and Wang (1990), who suggested that hypertext may inhibit readers' learning because the additional processing demands imposed by hyperlinks could overload cognitive processing capabilities. This may explain the results of a study which tested the working memory of undergraduate students and their performance on a comprehension test following the reading of an instructional text presented on

hypertext (Burin et al., 2015). It found that hypertext readers with high working memory capacity had higher comprehension scores and more efficient navigation behaviours than those with low capacity.

Further evidence for this comes from experiments which compare learning across study media, by showing how the additional demands imposed on working memory by the processing of hyperlinks and an incoherent structure may lead to an increase in cognitive load. For instance, Lee and Tedder (2003) tested how different types of hypertext affected readers' recall. Participants read an informational text across three digital text formats: traditional text (which imitated print text by presenting each page individually, and in order), structured hypertext, and networked hypertext. They found that traditional text readers had higher recall scores than readers of both hypertext formats. In agreement with others' findings, networked hypertext readers with low working memory capacity had lower reading comprehension scores than scrolling text and highly structured hypertext readers (Amadieu et al., 2010; Blom et al., 2018; Potelle & Rouet, 2003). A follow-up study explored how text formats affect readers' comprehension and feeling of disorientation based on their experience with hypertext (Lee & Tedder, 2004). Participants read three unrelated texts in one of three digital formats: scrolling text, expanding hypertext, and networked hypertext. Networked hypertext readers reported the most disorientation, and those with low prior knowledge and low working memory capacity produced lower recall scores than those who read scrolling text.

To conclude this section, digital text reading can place additional demands on attention and working memory due to non-linear features not present in traditional print text reading (i.e., hyperlinks), impairing performance on reading

comprehension tasks. While some features of digital texts may help improve reading experiences for some individuals (e.g., individualisation of text and screen properties), other features can affect attentional processes and overburden working memory. For example, the Process Model of hypertext reading describes how readers constantly engage in decision making processes when interacting with hyperlinks (DeStefano & LeFevre, 2007). Deciding whether to click links immediately or later, remembering their location within the text and what information they lead to, in addition to assessing their relevancy and relation to other concepts can increase the amount of cognitive load when reading. An increase in cognitive load means the readers' ability to use attentional and working memory resources for activities like locating unread information, implementing learned reading strategies, and integrating prior knowledge is reduced.

2.3 The Role of Metacognition

Metacognition can be succinctly described as 'cognition about one's own cognition', which includes one's stored knowledge and beliefs about themselves and others (Furnes & Norman, 2015; Son & Metcalfe, 2000). This includes processes related to self-regulation and monitoring one's own behaviour when, for example, making the decision to read a text more than once if one feels that comprehension was low. Self-regulation refers to the extent to which a learner is 'metacognitively, motivationally and behaviourally active' in their own learning process and involves active monitoring and control over the cognitive processes engaged during learning to regulate behaviour (Brown; 1987; Koriat, 2012; Zimmerman, 1986). Metacognitive processes are usually associated with higher-level thinking, with deep comprehension of a text being necessary to make accurate judgements about how much they know about a text. However, a recent review of research on

metacognition and reading found that individuals generally engage more in shallow processes when reading digital texts versus print texts (Wylie et al., 2018).

Having better metacognitive skills (e.g., strategies for learning, monitoring) has been found to be a significant predictor of learning from hypertext. Schwartz et al. (2004) assessed such skills in a sample of nine to 17-year-olds and measured their learning from networked and hierarchical text structures. They found that strategizing and monitoring predicted better performance in the networked hypertext condition only, suggesting metacognitive skills are more important for more demanding text structures. Another study explored metacognitive monitoring, deeper-level processing, and methods for overcoming screen inferiority in undergraduate students reading an informational hypertext (Lauterman & Ackerman, 2014). Participants were generally inaccurate in making judgements about their own learning on hypertext. Screen inferiority effects could be overcome by practicing the challenging reading comprehension task and encouraging participants to engage in more in-depth processes by asking having them produce keywords summarising the text's essence.

Other research has investigated the differences for learning and metacognitive experience in comparisons of reading in digital and non-digital contexts. For example, Ackerman and Lauterman (2012) examined the effects of time pressure on learning texts on screen versus on paper across two experiments. In Experiment 1, 80 undergraduates read five online texts containing information about various topics. Their study time, predictions of performance, and multiple-choice test scores were recorded. Half were given a set time in which to read the information (seven minutes), and the other half were given no regulation on reading time. Comprehension test scores were higher for those reading on paper than on

screen when reading under time pressure, but there were no differences under free regulation. Overall, the paper learning condition was the most efficient (based on a calculation of points per minute). Their results support the notion that individuals have difficulty in self-regulating their learning on screen, while highlighting that the time in which one has to learn new information might also affect their comprehension, especially when learning from hypertext. Indeed, Lee and Tedder's (2003) research found that when the total time spent on reading was controlled for, the previously found difference in comprehension scores between the two types of hypertexts (i.e., that networked hypertext readers had lower comprehension than linear text readers) disappeared.

Ackerman and Goldsmith (2012) compared the metacognitive monitoring and control of undergraduate students learning from either paper or screen. They found that there was an overall screen inferiority effect for comprehension scores, in addition to screen learners reporting an overconfidence in their predicted scores. However, some have challenged findings of screen inferiority. For instance, one study investigated whether metacognitive monitoring accuracy for four informational texts was influenced by whether the texts were presented on paper, PC, an iPad or a Kindle (Norman & Furnes, 2016). The researchers recruited 100 undergraduates and assigned them to one of four reading conditions in which participants read the same informal text. Metacognitive experiences were assessed through predictions of performance, judgements of learning, confidence ratings, and assessed recognition performance on a factual recall task. The researchers found that study media had no consistent effect on metacognitive calibration (the difference between participants' predictions of performance and their comprehension scores). The findings of this study contrast with previous 'screen inferiority' studies which demonstrate a lower

correspondence between metacognitive experience (e.g., monitoring and control) and learning outcome (comprehension performance) from on-screen learning versus print text learning (Ackerman & Goldsmith, 2011). As a result, they suggested that future studies should use different types of digital texts, especially non-linear formats such as hypertext and assess metacognitive regulation across both media. This would be more representative of the complex learning environments readers might engage with when reading new information.

2.4 Chapter Summary

The aim of this chapter was to explore the key cognitive processes involved in print and digital text comprehension. It identified that attention, working memory, and metacognition are all important for the comprehension of texts. Traditional theories of reading comprehension have shown that integration of prior knowledge, construction of coherent mental representations, and the ability to extract meaning contribute to deeper levels of understanding.

Within the context of the C-I model, hypertext may impact readers' ability to form coherent structural and situational mental representations of a text. In addition, the added cognitive load of hypertext reading may overburden readers, especially those with lower working memory ability. This may disrupt working memory processes and negatively impact comprehension and the ability to connect ideas. Previous research has found that hypertext readers have lower comprehension scores than those reading print text. In particular, inferential comprehension has been found to be weaker for hypertext than print text. However, gaps in knowledge about the comparative impact of different types of hypertext on textual and inferential comprehension exist. Therefore, future research could investigate working memory,

metacognition, and comprehension in readers of different types of hypertext, and compare the results to print text readers in light of models of reading comprehension. There is also a need for further research into how individuals navigate hypertext. Chapter 3 will explore the navigation of digital texts, how best to measure navigation, the individual differences that contribute to navigation beneficial for comprehension (e.g., reading skill, working memory, prior knowledge, reading strategies), and how to facilitate navigation of hypertext.

Chapter 3: Navigating Texts in the Digital Era

Upon hearing the term ‘navigation’, one might envisage a naval captain directing their ship across the ocean, an orienteer traversing unfamiliar terrain, or a driver following a route as instructed by their car’s satellite guidance system. In reality, navigation refers to the science of determining position and direction, and the process of monitoring and controlling movement (Hofmann-Wellenhof et al., 2007). While this definition originally related to the method of getting people or vehicles from one place to another, it has since broadened to apply to other contexts. In digital environments, navigation refers to readers’ behaviours such as their selection and ordering of information online. For print texts, readers typically navigate through books in a predictable and logical way: making forwards and backwards movements to get closer to, or further from, the beginning or end of the text. However, some digital texts present information in a non-linear format where the beginning, middle, and end sections are not as easily located, as the overall text structure is more abstract.

This chapter will explore the ways in which readers navigate hypertext. It will describe some of the most frequently used methodology for measuring navigation in the relevant research literature, and discuss the individual differences of readers which may contribute to either advantageous or disadvantageous behaviours for comprehension. The chapter will conclude by exploring ways in which researchers have aimed to facilitate navigation of hypertexts in order to overcome common difficulties of reading and learning from this medium.

3.1 'Lost in Hyperspace'

The World Wide Web is a vast information space with, as of January 2017, had just under two billion individual webpages (Liedke, 2019). Hypertext systems include multiple webpages which are interconnected and accessible through hyperlinks (Nelson, 1965; Nelson, 1987). These systems are non-linear and non-sequential, meaning that readers often must mentally organise and synthesise information themselves to prevent getting 'lost in hyperspace', a phenomenon which has been well-documented in the literature (Cangoz & Altun, 2012; Hardman & Edwards, 1989; Theng & Thimbleby, 1998; Theng et al., 1996). Learning from hypertext relies on comprehension processes that attempt to establish coherence between multiple sections of information (Coiro et al., 2011; Foltz et al., 1996). Establishing and maintaining coherence is important when reading because readers construct a mental representation of the overall semantic organisation of a text in order to achieve good comprehension (Kintsch, 1998; see, Chapter 2, for more information on theories of reading comprehension).

However, deciding which hyperlinks to click, identifying and updating a mental representation of text structure, and connecting large amounts of information, can overwhelm readers resulting in significant disorientation (Amadieu et al., 2010; Bayazit et al., 2018; McDonald & Stevenson, 1998; Sandberg, 2013; Shapiro & Niederhauser, 2004; Spiro et al., 2012). There are two categories of hypertext disorientation: conceptual disorientation and structural disorientation. Conceptual disorientation occurs when learners are unable to relate different concepts, resulting in them attaining disjointed segments of knowledge rather than coherent knowledge structures (Dias & Sousa, 1997). Conversely, structural disorientation occurs when

learners are unable to specify their location and get lost within the hypertext (Conklin, 1987).

In order to overcome disorientation effects, hypertext readers may have to recruit extra cognitive resources to cope with the additional demands placed on attentional and working memory processes (DeStefano & Lefevre, 2007). For some readers this might overburden their limited-capacity memory stores, inhibiting higher-level processes such as inference-making and connecting ideas across multiple sections of the text. These higher-level processes are necessary for gaining a deeper comprehension of a text. Overburdened working memory resources may also affect navigational behaviours in hypertext because readers may not be able to recall which sections contained information related to their reading goal. Furthermore, disorientation caused by the complex non-linear nature of this format may lead to time spent reading irrelevant information or the reader missing some sections as they click hyperlinks and attempt to build a coherent mental representation of text structure. Therefore, in keeping with the navigation metaphor, it is vital that readers are able to easily traverse the landscape of complex digital reading environments, monitor and control their position in a hypertext relative to other information, and follow a route of hyperlinks according to their reading goal to achieve good comprehension.

A recent review synthesised previous findings on the comprehension of digital texts, and identified three main competencies of interactions with hypertext: navigation, integration, and evaluation (Salmerón et al., 2018). Firstly, navigation in digital contexts describes how hypertext readers access information across multiple sections of text; in particular, the order in which they select individual webpages pages (Lawless & Schrader, 2008). Marchionini (1995) distinguished between two

typical types of navigation in hypertexts: searching and browsing. Searching was defined as an analytical problem-solving process in which selective strategies are used to decide which link will lead to target information, whereas browsing related more to exploring hypertext without trying to locate specific information. Navigation also involves visual scanning for goal-relevant information and sequencing relevant pages through hyperlink selections (Cho, 2014). Previous research exploring hypertext navigation has found that spending more time on sections relevant to a study goal, identifying main ideas, progressing through the text in a linear direction, and spending greater time on individual pages are positively related to comprehension performance (Blom et al., 2018; Naumann, 2010; Salmerón & García, 2011; Salmerón et al., 2010).

For example, Naumann and colleagues' (2007) study explored how undergraduates navigated through an expository hierarchical hypertext, finding significant positive correlations between the number of relevant page visits and textual and inferential comprehension scores. Similarly, the PISA 2009 digital reading assessment (OECD, 2011) found that task-relevant navigation was predictive of a range of learning outcomes among students across several countries.

Secondly, integration involves the activation and updating of prior knowledge facilitated by working memory processes. As readers progress through a text, they make inferences based on what they already know in order to better understand new information. According to the Construction-Integration (C-I) model, textual comprehension is the result of a task-driven construction process in which readers form mental representations (Kintsch, 1988; Kintsch & van Dijk, 1978). Construction refers to the activation of information contained within the text and includes the initial activation of knowledge (both relevant and irrelevant).

Integration refers to the spreading of activation, where relevant prior knowledge is integrated with new information contained within a text. This relates to navigation of hypertexts because information is presented non-linearly with information segmented into many parts, disrupting the construction of coherent mental representations necessary for deeper comprehension.

Evidence that deeper comprehension is impacted by hypertext was found in a review by Delgado and colleagues (2018), which revealed that many studies investigating the differences between print and hypertext comprehension found that hypertext readers were particularly disadvantaged when answering inferential comprehension items. Inferential comprehension items often require the integration of prior knowledge for the reader to make judgements about a text (see Chapter 1 for descriptions of types of comprehension). Navigational difficulties, and therefore the formation of an incoherent situation model, may account for weaker integration in hypertext.

Lastly, evaluating is also an important skill when reading and navigating digital texts, as learners often must judge the relevance, credibility, and utility of sources when seeking information online (Goldhammer et al., 2013). For example, a learner may have to decide the trustworthiness and relevance of thousands of 'hits' on a search engine results page (SERP) in order to locate information relevant to their learning goal. Stadtler and Bromme's (2014) content-source-integration model suggests readers make first-hand and second-hand decisions about the trustworthiness of knowledge claims. First-hand decisions involve comparing what the reader believes to be true based on their knowledge, whereas second-hand decisions involve the scrutiny of the source (i.e., who is making the knowledge claim?). Evaluating the relevance of hyperlinks and text information is as relevant

for closed-hypertexts (systems with limited number of pages mainly relating to a specific topic), as it is for open-hypertexts (websites like Wikipedia with millions of pages and hyperlinks that may take the reader to unrelated information). This is because a reading goal may require the reader of a closed-hypertext to locate or recall specific information, meaning the reader must decide which hyperlinks will lead to this information. In addition, the reader may already have some prior knowledge about a topic, so may decide not to follow a navigation path leading to information they know about, in favour of following one which leads to information they do not.

A conclusion of the review by Salmerón and colleagues (2018) was that previous research has mainly examined the three competencies of navigation, integration, and evaluation independently. A study by Hahnel et al. (2016) investigated the relationship between these skills by analysing teenagers' ability to select webpages in a SERP task and navigate hypertext. Although the ability to select relevant webpages was positively correlated with efficient navigation, there was no correlation when accounting for single text comprehension skills.. This suggests that navigation, integration, and evaluation are, in part, developed as separate skills. Future research should further investigate how readers navigate, integrate, and evaluate in hypertext.

To summarise this section, assessing navigation of digital texts is important for understanding how readers interact with and learn from complex non-linear information. Navigation of hypertext involves multiple processes such as searching, integration, and evaluation. The non-sequential nature of hypertext can result in readers becoming disorientated and unable to easily locate target information, leading to the well-documented 'lost in hyperspace' phenomenon. Research has

shown positive relations between efficient hypertext navigation (e.g., relevant hyperlink selections, efficient use of time) and comprehension performance. Studies measuring hypertext navigation attempt to show how behaviours relate to learning outcomes, including comprehension and recall.

3.2 Measuring Navigation of Digital Texts

There are many ways in which hypertext reading differs from traditional print text reading; a major difference being that hypertext readers can access different sections of a text in a self-determined manner. For example, while print texts are organised in a fixed way (with pages occupying a physical space near either the front, middle, or back of a book), the individual pages of a hypertext can be accessed in multiple ways depending on which navigational path the reader chooses to take. According to Winne's (1995; 2001) model of Self-Regulated Learning (SRL), readers are active participants in the learning process who set a goal or standard to guide learning based on task conditions (e.g., a specific reading goal), and on cognitive conditions (e.g., their prior knowledge). The SRL model was originally developed for traditional linear text, but has since been applied to hypertext reading because selecting appropriate hyperlinks, avoiding irrelevant hypermedia features, and deciding the order in which to progress through the text demonstrates the need for hypertext readers to self-regulate their learning to a degree greater than linear text reading (Azevedo et al., 2008; Rouet, 1992).

Following the SRL model, a study explored the role of self-regulation in strategies that low and high prior knowledge readers use to decide the order in which to read different hypertext sections (Salmerón, Kintsch, & Kintsch, 2010). Three main strategies for link selection were investigated: link screen position, link

interest, and the semantic relation between links. Low knowledge readers who selected hyperlinks in a semantically coherent sequence performed better on inferencing comprehension items, whereas low knowledge readers who selected links based on where they were located on the screen (i.e., the link that appeared on screen first) had lower comprehension scores. These results highlight the importance of efficient navigation decision for hypertext comprehension. Identifying which navigational behaviours are dis/advantageous for learning from hypertext can lead to recommendations of how to improve hypertexts to facilitate good navigation.

The following sections will present some of the most commonly used methods for measuring hypertext navigation in the relevant research literature. They will describe how log file, eye-tracking, and think-aloud protocols are used to assess how learners interact with hypertext and how navigation behaviour is related to learning outcomes. The strengths and weaknesses of each method will be outlined.

3.2.1 Log File Analysis

One of the most common ways of measuring readers' navigation of digital texts is to collect log file information. Log files are a useful tool for identifying patterns in readers' behaviours such as how often they visit individual pages and in what order they progress through the text. They record ordered sequences of actions including which hyperlinks readers select and other interactions with interactive hypermedia features (e.g., clicking a 'next page' button). The time spent on each page and counts of individual page visits (called 'single-visit' measures) are also often recorded by log files. A major advantage of using this method to investigate learners' interaction with hypertext is that data collection is unobtrusive and does not interfere with participants' reading tasks. Data collection can also be automated (i.e.,

a computer collects navigation information automatically and in real-time) so that a wealth of information about navigation behaviour can be collected relatively easily. Naumann (2008) conducted a meta-analysis of how log file analysis methods have been used in the hypertext literature. The analysis found that 68% of all studies using log files to investigate learners' behaviour through hypertext included single-visit measures, which constituted the most common measure of hypertext navigation. However, very few studies used log files to generate more complex multiple-visit measures such as sequences of page visits (e.g., recurring sequences of page visits) and backtracks in navigation (i.e., immediately returning to a previously read page).

An example of log file analysis being used to assess navigation behaviour through hypertext is in a study which investigated the relationship between children's reading skills and navigation strategies in hypertext (Salmerón & García, 2011). Reading skills were identified as the ability to decode information, identify statements, and integrate ideas without explicit attention (Perfetti, 1994). The log files recorded participants' hyperlink selection (navigation path) and reading times (overall reading time and time spent on each page). The study found that each of the three reading skills (decoding, identifying, integrating) predicted relevant link selection.

Naumann and Salmerón (2016) also used log files to explore the effect of page selection on hypertext comprehension and found a positive relationship between relevant page selection and hypertext comprehension. Similarly, Blom and colleagues (2018) used log files to test the effect of a graphical overview (with or without) and text presentation (paged hypertext or networked hypertext) on navigation and comprehension. The log files recorded how long readers remained on each page, the order of paragraphs read (linearity of navigation), and the total

reading time. They found that students spent more reading time per page on texts with an overview than those without. Furthermore, paged hypertext was read in a linear direction (i.e., from start to finish), whereas the networked hypertext was read out of order and with many 'jumps' back and forward in the text.

Log files are used abundantly in the relevant research literature, as they are a useful tool for helping identify patterns in hypertext readers' navigation behaviour. They record information about how long a reader spends on individual pages, how many 'clicks' they make, which hyperlinks are selected, and the order in which they progress through the text. The empirical studies presented in this thesis will use log files to measure these behaviours, and explore how they are related to hypertext comprehension.

3.2.2 Eye-Tracking and Think-Aloud Protocols

Other methods of measuring readers' navigation of hypertext are eye-tracking (e.g., Salmerón et al., 2009; Walhout et al., 2015) and think-aloud (e.g., Afflerbach, 2000; Wang, 2016) procedures. These are sometimes used in combination alongside log files to provide additional information about the comprehension of online texts that cannot be provided by log files alone (Kaakinen, & Hyona, 2005; Salmerón et al., 2017). For example, log files that record the amount of time spent on individual hypertext pages may reveal that two participants spent the same amount of time reading one page. However, this does not provide explicit information about what each reader did on the page. For instance, one reader may have spent the time quickly reading and re-reading the information without thinking much about how it relates to what the reader already knows (i.e., shallow reading), whereas the other reader may have moved more slowly through the

text and thought more about the connections between the information found on the current page with information located elsewhere (i.e., deep reading). These different reading experiences are reflected in the log file analysis as the same amount of time, and so conclusions made about the readers' behaviour are based on inferences about how much of the text they both read. Therefore, other procedures may be used to supplement eye-tracking methods.

Eye-tracking can be used to help identify where on a page the reader is fixated. This helps gather information about which text parts they are reading, and whether the reader is engaged in scanning or deep reading processes (Kaakinen & Hyönä, 2005). Used in combination with eye-tracking methods, think-aloud protocols elucidate further information on students' behaviours and strategies while learning from hypertext (Salmerón et al., 2017). For example, retrospective think-aloud methods are conducted after a learning task has been completed, and involve interviews that ask learners about their general reading strategies and how they applied them during a reading task (Van Den Haak et al., 2003). Often, this involves showing the reader eye-tracking information from the reading task and asking them to explain what they were thinking when looking at different stages of the reading task.

One potential disadvantage of this method is that some learners may not be able to accurately identify or articulate the reading strategies or behaviours they employ when completing reading tasks. Alternatively, concurrent think-aloud (CTA) methods are also sometimes used in combination with eye-tracking methods, and is conducted while the learner is engaged in a reading task (Elling et al., 2012). Using this technique, participants may be asked to verbalise their thoughts and strategies in real-time (i.e., as they are actively engaged in a reading task). However,

this may disrupt the reading task itself, thereby disrupting the formation of coherent mental representations necessary for deeper comprehension (Kintsch, 1988).

Some researchers use a combination of eye-tracking and think-aloud methods to gain a deeper understanding of what log file information shows. For example, Salmerón, and colleagues (2017) explored how high school students articulate scanning and deeper processing of information while answering questions in an internet problem-solving task using a Wikipedia document by analysing retrospective think-aloud protocols and eye-tracking measures. They found that scanning of information (versus deep processing) led to poorer hypertext comprehension. Log-files revealed that highly skilled readers quickly scanned and revisited less often pages of the hypertext containing irrelevant information for their reading goal. The results indicated that different navigation behaviours are related to comprehension in hypertext; scanning results in more shallow comprehension, whereas more careful navigation consisting of relevant link selections leads to deeper comprehension. Furthermore, Trevors and colleagues (2016) used both eye-tracking and think-aloud protocols to supplement log-file analysis across two studies, and found that prior knowledge and epistemic self-efficacy were important in detecting and resolving discrepancies in multimedia learning environments.

However, the reliability and validity of verbalisations in relation to mental processes during reading has been challenged. For example, Ericsson and Simon's (1980) study found that participants who are asked to verbalise information that would not otherwise be attended to can be unreliable. The researchers suggested that, since thoughts are considered sequential, it may be difficult for individuals to accurately recall every sequence of thoughts that led to a decision. Difficulty in recalling sequences of thoughts is reflected in the results of other studies that have

found a high percentage of silences during both CTA and retrospective think-aloud protocols (Elling et al., 2012; Ericsson & Simon, 1993). Furthermore, Cooke's (2010) study used a combination of CTA and eye-tracking protocols to assess the validity of CTA, and found that 77% of participants' verbalisations referred to things that could otherwise be observed by other methods. Therefore, log-files alone may provide sufficient information on hypertext readers' navigational behaviour and reading decisions.

To conclude this section, there are many ways with which to measure hypertext navigation. Log files record information including hyperlink selections, time spent on individual pages, number of clicks, and order of page visits. This can be used to create navigation profiles of hypertext readers, which may be useful for identifying which behaviours are most advantageous for comprehension.

3.3 Individual Differences in Navigation Behaviour

Reader navigation through hypertext can be influenced by many factors. Reading skill, working memory ability, topic knowledge, and different reading strategies (e.g., scanning, deep reading, rehearsal) are just some individual differences that may contribute to the ways in which readers interact with hypertext. This section will explore the most relevant research literature investigating these factors.

3.3.1 Reading Skill

One factor that might influence the ways in which readers navigate through hypertext is reading skill. Reading skill encompasses a variety of offline and online comprehension abilities such as evaluating, integrating, and digital competency (e.g., knowledge of hypermedia features, ability to form coherent relations between

hypertext pages). Previous research has found a positive relationship between the reading comprehension skills of highly proficient readers and deep processing of relevant sections of a hypertext (Coiro & Dobler, 2007; Zhang & Duke, 2008).

A study investigated the effects of navigation and offline comprehension skill on digital reading performance in high school students aged between 11-17 (Naumann & Salmerón, 2016). Navigation was measured by log files which recorded the percentage of task-relevant and task-irrelevant pages visited during several question-and-answer digital reading tasks. Specifically, participants completed the web portal test from the Programme for International Student Assessment (PISA) framework wherein they navigated through several webpages to answer items related to accessing and retrieving, integrating, and evaluating, textual information (OECD, 2009). A positive effect of offline comprehension skill (i.e., print text comprehension) and relevant page selection was found, suggesting that while navigation plays a crucial role in digital reading performance, the effect is moderated by traditional offline comprehension skills. Therefore, instructional programs which strengthen students' navigation processes should consider the impact of comprehension skills. For example, students with weaker comprehension may benefit from instruction targeted at supporting their hyperlink selection decisions.

Another study investigated the effects of students' reading skills and navigation behaviour on reading and comprehending digital text (Hahnel et al., 2016). The researchers explored a subsample of 15-year-old German students who participated in the 2012 Programme for International Student Assessment (PISA). They found that students' computer skills (familiarity and competency of using computers to read texts) and their ability to evaluate online information was

positively related to their comprehension of hypertext (over and above performance for linear texts). Moreover, evaluation skills were positively related to the accessing of pages containing task-relevant information (recorded by log-files), further showing that reading skills may be important for the processing of hypertext.

A limitation of these studies is that they investigate the impact of reading skills on the navigation of highly structured digital reading scenarios (e.g., web forums, standardised reading tasks, multiple documents). Less is known about how students navigate more complex hypertexts such as networked hypertexts, and how reading skills including the ability to integrate prior knowledge and remember where information is located are related to comprehension.

3.3.2 Working Memory

The role of attention and working memory in the comprehension and navigation of hypertext has been discussed in a previous chapter (see, Chapter 2). To summarise, research has consistently found that the additional demands placed on working memory due to the decision-making processes associated with hyperlink selection impacts comprehension (for a review, see DeStefano & Lefevre, 2007). For example, Burin and colleagues (2015) explored the relationship between working memory, prior knowledge (high prior knowledge text versus low prior knowledge text), hypertext type (hierarchical versus networked; see Chapter 1 for descriptions of different types of hypertext) and navigation behaviour in undergraduates. Using log-files, they found that high prior knowledge texts led to more pages visited, more non-linear jumps in reading, and frequent returns to the overview presented in the homepage. For comprehension, participants with high prior knowledge and high working memory capacity performed better than those

with low prior knowledge and working memory capacity. There were also interaction effects: for the high prior knowledge text, high working memory readers spent a greater amount of time on the reading task than low working memory readers. These findings support others' work that shows readers high in working memory capacity perform better on recall comprehension, experience less disorientation, and navigate more efficiently when navigating through complex networked hypertexts (Lee & Tedder 2003; Lee & Tedder, 2004).

In addition, Vörös et al. (2008) explored the role of visuospatial working memory and the phonological loop in navigation of structured hypertext. They predicted that the mental representation of the text layout would be better elaborated in the presence of a verbal concurrent task or no concurrent task than in the presence a visuospatial concurrent task. This is because in the first two cases, the two concurrent tasks do not have to compete for the limited capacity of the same working memory storage unit. They found that both the visuospatial and phonological loop components of working memory had an effect on route knowledge (i.e., sequences of hyperlinks to reach target pages, as measured by log-files).

An explanation for these results may be that those with higher working memory capacities can remember more information about the hyperlinks than those with lower capacities. Remembering the location and content (underlined words) of a hyperlink may help comprehension because it enables the reader to easily relocate information rather than clicking on many hyperlinks to find it. Those with a greater capacity may be able to retain this information, update it as reading progresses (by thinking about how it relates to other hyperlinks), and retrieve it later, to a greater extent than those with lower capacities. In addition, remembering which hyperlinks have already been selected will allow for better evaluations of whether future

hyperlinks will lead to relevant or new information, which may get the reader closer to their reading goal. In summary, working memory plays an important role in readers' comprehension and navigation of hypertext. The additional load of decision-making associated with link selection may cognitively burden those with higher working memory capacity less than those with lower working memory capacity, because they are able to store and manipulate more information in their working memory stores.

3.3.3 Prior knowledge

According to Britton and Gulgoz (1991), the reader's background knowledge is one of the primary factors that influence comprehension. Using Kintsch's reading comprehension model (Kintsch, 1988; van Dijk & Kintsch, 1983), they suggested that new information is incorporated into pre-existing knowledge structures through the activation of prior knowledge during reading. Foltz (1996) found that the amount of background knowledge can differentially impact the comprehension of hypertext readers, and suggested that high knowledge readers have more accurate conceptual structures in which to integrate new information, resulting in better recall. However, as previously mentioned, the additional cognitive load generated by hyperlinks, and the disorientation caused by information being presented in non-sequential segments may inhibit the action of these integration processes, resulting in weaker comprehension for both low and high prior knowledge hypertext readers (DeStefano & LeFevre, 2007). The absence of an explicit text structure means readers must develop their own conceptual structure during reading by navigating and frequently updating their knowledge of how information is related. Therefore, navigation decisions in hypertext are partly influenced by how much the reader

already knows, and whether they have a pre-existing conceptual structure in which to integrate.

Hypertext structure has been found to impact the reading comprehension of low prior knowledge readers in particular. Calisir and Gurel (2003) investigated the influence of text structure (linear, hierarchical hypertext, mixed hypertext) and readers' prior knowledge on navigation (browsing) and reading comprehension, and found that hierarchical hypertext was most suited to low prior knowledge readers overall, likely because this format provides a clear organisational structure. However, for navigation they found equivalence between all three conditions. Calisir and colleagues (2008) conducted a follow-up experiment with a similar methodology, and also found that low prior knowledge readers of hierarchical hypertext performed better than the other conditions. They also concluded that domain knowledge helped those with high prior knowledge in understanding and conceptualising the structure of the document. This is also reflected in the finding that low prior knowledge readers opened more nodes (i.e., clicked on more links) than high prior knowledge readers during browsing; confirming others' findings that low prior knowledge hypertext readers click more hyperlinks, likely because they attempt to construct a conceptual structure (Blom et al., 2018; McDonald & Stevenson, 1998).

Furthermore, a study investigated the effects of prior knowledge and type of hypertext (hierarchical versus networked) on disorientation, cognitive load, and comprehension in 24 adults (Amadieu, et al., 2009). Low prior knowledge readers experienced greater disorientation and demonstrated less efficient navigation when reading from the more complex networked hypertext versus the hierarchical hypertext. There was no effect of hypertext structure on disorientation for those with

high prior knowledge. These results show that readers with low prior knowledge may be more susceptible to disorientation effects when reading hypertext.

However, other findings related to the role of prior knowledge for comprehension and navigation of hypertext have been inconsistent. For example, Sullivan and Puntambeker (2015) explored the impact of prior knowledge and reading comprehension ability on navigation and comprehension among eighth-grade students, and identified no significant relationships between prior knowledge and navigation or learning. A possible explanation for this is that the hypertext may have been structured well enough to provide both low and high prior knowledge readers with a cohesive mental representation of the text structure, therefore enabling both groups to learn the content to a similar extent.

In summary, prior knowledge is important for understanding navigation of hypertext. When a hypertext provides the reader with an explicit structure that is easy to navigate, the need for them to construct a macrostructure in which to integrate what they already know is diminished, freeing up cognitive resources for making navigation decisions based on their prior knowledge (Lorch & Lorch, 1996). Since constructing a macrostructure can be cognitively demanding, low prior knowledge readers may be especially disadvantaged in poorly-structured hypertext environments because they do not have an existing conceptual structure in which to integrate what they already know.

In contrast, if a reader has a pre-existing mental representation of knowledge, they might actively seek information that either confirms or extends that prior knowledge. However, determining what constitutes 'good' navigation decisions depends on the reading goals of both the task and the individual. For example, in

some reading situations (e.g., browsing recreationally), readers may be content to 'get lost' in hypertext and discover new relations for themselves. Alternatively, other reading situations may require specific information to be learned (e.g., when studying for a test). Future research should investigate a range of hypertexts to explore the impact of explicit (e.g., structured hypertext) or abstract (e.g., networked hypertext) text structures on the navigation and comprehension of low and high prior knowledge readers.

3.3.4 Use of Reading Strategies

As with the reader variables already discussed (e.g., reading skill, working memory, prior knowledge), the relationship between strategy use and comprehension of hypertexts texts has been widely reported (Barab et al., 1997; Britt et al., 1996; Foltz, 2012; Lawless & Kulikowich, 1996, 1998; Magliano et al., 1999; McNamara & Scott, 1999; Rouet et al., 1997; Salmerón, & García, 2011; Salmerón, Kintsch, & Kintsch, 2010; Shang, 2016; Trabasso & Magliano, 1996). Some of the main reading strategies researchers have investigated range from shallow strategies (e.g., scanning, identifying words or sentences) to deep strategies (e.g., making inferences, forming connections, evaluating). Using log files and other approaches, researchers have explored how hypertext readers' self-reported reading strategies matched up with their actual navigational behaviours. These are then compared to comprehension performance to identify dis/advantageous strategies for comprehension.

In their influential studies, Lawless and Kulikowich (1996; 1998) used a cluster analysis method to assess the navigational profiles of hypertext readers. From this, they were able to identify three distinct navigational groups: knowledge

seekers, feature explorers, and apathetic hypertext users. Firstly, feature explorers spend the majority of their reading time attending to the unique features of hypertext such as images and other multimedia. Secondly, knowledge seekers largely spend their time on content-related sections, focusing on knowledge acquisition from the words themselves. Lastly, apathetic users spend short intervals of time on content-related sections of a text and appear to follow a random reading order, opting to navigate through the text with no apparent method or strategy. Of these groups, knowledge seekers scored the highest on measures of reading comprehension.

Since these early studies, other categories of hypertext navigation have been suggested in the literature. For example, Salmerón & García (2011) expanded on work conducted with older populations to show that young students also use two distinct navigation strategies: cohesive hyperlinking (Foltz, 1996), and initial overview processing (Salmerón et al., 2009). Cohesive hyperlinking refers to the selecting of highly related hyperlinks to maximise semantic relationship between sections, while initial overview processing refers to when readers spend time familiarising themselves with the hypertext structure and overview before reading the text.

In summary of this section on individual differences in navigation behaviour, previous research suggests that there are two main categories of reading strategies. The deeper strategies involve making inferences based on prior knowledge, making connections between different parts of the text, and making linear navigation decisions, which all contribute to greater comprehension scores. In contrast, shallow strategies involving skimming, spending small amounts of time on pages, and making non-linear navigation decisions, which all contribute to weaker comprehension. Furthermore, individual differences including reading skill,

working memory ability, and prior knowledge may all impact hypertext navigation. Future studies should continue to investigate the differences in navigation behaviour between high and low working memory and prior knowledge readers and the consequences for comprehension.

3.4 Facilitating Navigation of Hypertexts

As previously mentioned, hypertext navigation involves deciding which hyperlinks to select, how long to spend on individual pages, and the order in which to progress through the text. However, hypertext readers may find it difficult to organise information from different sections in a coherent way. This may result in readers becoming disorientated and them having to rely on other text features (e.g., page numbers, 'back to homepage' buttons) or on their prior knowledge to form a coherent representation of the text structure (Baccino et al., 2008; Cangoz & Altun, 2012; Mcdonald & Stevenson, 1998). Consequently, methods designed to facilitate hypertext usage have been proposed in the research literature. This section will explore some of the most common methods for supporting readers' navigation through hypertext, including design features and strategy training.

3.4.1 Graphical Overviews

A graphical overview is a visual guide designed to represent hypertext structure, and how the multiple individual pages that comprise it are interconnected. These overviews include features including arrows depicting the possible navigation choices to/from pages (representing hyperlinks), and the title/subheading of each page to help the reader identify which page they are currently on. Early research on graphical overviews suggested that they may be beneficial for navigation and learning. Mayer's (1979) Assimilation Theory proposed that graphical overviews

provide an organisational framework which may facilitate the reading of more difficult texts. They do this by increasing the salience of the hypertext's structure, enabling readers to construct an accurate mental representation according to the situation model.

According to this theory, graphical overviews may be especially beneficial for low prior knowledge students, because the presence of an overview would diminish the need to build a macrostructure in which to integrate the main ideas of the text, freeing up cognitive resources for learning the information (Lorch & Lorch, 1996). The theory also suggests that overviews may facilitate comprehension only if students process them before processing text information and in reading situations where it is more difficult to learn, such as when the text structure is particularly complex (e.g., networked hypertexts) or when the readers' prior knowledge is low (Mayer & Bromage, 1980). High prior knowledge hypertext readers may also benefit from graphical overviews because the provision of an explicit macrostructure frees up cognitive resources for processes related to integrating and updating prior knowledge, and making more informed decisions about whether hyperlinks will lead to new or known information (depending on their reading goal).

Alternatively, Cognitive Flexibility Theory posits that an explicit representation of text structure may facilitate the flexible construction of a situation model which supports students' learning across multiple contexts and reading purposes (Spiro et al., 1989). This theory differs from the Assimilation Theory in that it places greater emphasis on the adaptive capacity of readers to identify conditions that could interfere with the task at hand (e.g., presence of overview), and change behaviour to match these conditions (e.g., attending to overview more). For example, if a graphical overview shows the reader that the next page they have just

visited is highly connected with other pages (signifying importance), then the reader may adapt to this by reading more slowly and employ more learning strategies (e.g., rehearsal). In contrast to these theories, the Active Processing Model suggests that highly structured overviews may inhibit readers' comprehension strategies (e.g., inferencing and relating to prior knowledge) by limiting the need for discovering relations between sections, something which has been related to weaker comprehension (Hofman & van Oostendorp, 1999; Shapiro, 1998). Research has explored the usefulness of graphical overviews for navigation and learning of hypertext in relation to these theoretical perspectives.

A study by Salmerón and colleagues (2009) investigated the order of graphical overview presentation and hypertext comprehension in low and high prior knowledge undergraduate students. Participants read 16 expository hypertexts on topics highly related to the participants' field of expertise (high knowledge), and on other topics (low knowledge). A graphical overview depicting the text structure was always available during the reading task so that participants could access it at any time, but the order in which it was presented differed so that it appeared either before or after the main text. The study found that reading an overview at the beginning of the hypertext was associated with increased comprehension of more difficult texts.

The findings were interpreted in light of the Assimilation Theory and the Active Processing Model. The researchers concluded that each of these perspectives is well suited to different learning situations; the Assimilation Theory explains situations where it is more difficult for students to learn from hypertexts (e.g., due to complex hypertext structure or low prior knowledge), whereas the Active Processing Model explains easier hypertext reading situations (e.g., highly structured hypertext or high prior knowledge). A limitation of this study is that, unlike 'normal'

hypertext, participants could not choose their own reading order. This meant that the researchers could not explore 'real' navigation decisions, and relate them to graphical overview usage.

A recent study investigated secondary school student's reading comprehension and navigation of networked hypertexts with and without a graphical overview (Blom et al., 2018). The study also explored whether prior knowledge and measures of working memory moderated the relationship between text type (hypertext versus linear digital text) and comprehension. Log files recorded total reading time, linearity of navigation (i.e., whenever a reader moved to a page one level up or below the current level in the hypertext structure) and the time spent on each page of the hypertext. They found that knowledge as measured by responses on multiple choice comprehension items was lower when reading networked hypertext versus linear text. In relation to the graphical overview, there was no relation with comprehension performance and no evidence that the presence of an overview led to a reduction in cognitive load. However, the graphical overview used was static rather than dynamic.

Static overviews cannot be interacted with and do not change during the reading task. In contrast, dynamic overviews change to reflect where the reader is currently located in the hypertext, enabling the reader to identify which navigation paths are possible from their current position. Previous research has found that static and dynamic overviews relate to different learning outcomes and levels of extraneous load (Amadieu et al., 2009; Bezdan et al., 2013). While dynamic overviews increase extraneous load, they also promote germane load because they promote the formation of a coherent representation of text structure as part of a situation model, thereby improving comprehension. Therefore, future studies should

continue to investigate the extent to which dynamic graphical overviews relate to comprehension, and how low and high prior knowledge readers navigate networked hypertexts.

Alternatively, concept maps are features of hypertext which have been proposed to reduce the cognitive requirements of navigation and comprehension, and they appear abundantly in the relevant research literature. Similar to graphical overview, they offer a pictorial representation of how the individual hypertext pages fit together, and may include arrows to represent hyperlink routes. Concept maps differ from graphical overviews, in that they specifically show the interrelations between concepts and show the reader which pages contain related ideas, whereas graphical overviews focus more on the organisational framework and explicit structure of the hypertext (Amadieu and Salmerón, 2014; Puntambeker et al., 2003).

Amadieu and Salmerón (2014) conducted a literature review examining the effects of concept maps on navigation comprehension and learning from hypertexts, concluding that concept maps support navigation by promoting the construction of a mental representation of the structure of hypertext; information about the interrelations between concept means readers are able to make more informed navigation decisions about which concepts they want to read, and how it relates to what they have already read/already know. They are particularly beneficial for learners with low reading skills and low prior knowledge as they do not greatly contribute to cognitive load, freeing up cognitive resources for comprehension processes. However, most of the concept maps reviewed were static and some could only be accessed once before the reading task took place rather than during. Therefore, further research should be conducted on dynamic concept maps and graphical overviews that appear during hypertext reading tasks.

While some hypermedia features such as graphical overviews and concept maps may support hypertext navigation and comprehension, other features may hamper performance. For example, some hypertexts include a text highlighting tool that allow readers to highlight sections of a text in a colour to make it stand out from the rest of the text. Li, Tseng, and Chen (2016) found that having the ability to highlight text on a networked hypertext resulted in significantly weaker reading comprehension performance and navigation (slower reading times, as shown by log files). The researchers suggested that the presence of the highlighting tool and the additional actions required to access it contributed to an increase in cognitive load, which may have overburdened some learners.

Another study explored whether blue hyperlinks on the Web causes disruption to reading, and found that the presence of a single coloured word within a written sentence reduced the likelihood that the word was skipped (Fitzsimmons, 2017). However, when the reader knew that the coloured word was explicitly a hyperlink, it was found that they fixated more on the word. Moreover, gaze fixation time was increased especially when low frequency words contained a hyperlink. This has many implications for the design of hypertext. For instance, Fitzsimmons (2017) suggested that if a low frequency word is also a hyperlink, readers may have to recruit extra cognitive resources to evaluate the mismatch between the presence of a hyperlink (suggesting importance) and low frequency words (that are potentially less consequential). If the hypertext design incorporates numerous hyperlinks which the reader must evaluate, then performance may suffer. Therefore, future research should explore hypertext features and text design aimed at facilitating hypertext navigation and comprehension, and assess their impact on the comprehension of low and high prior knowledge and working memory participants.

3.4.2 Strategy Training

An alternative way to facilitate readers' navigation of hypertext is to introduce strategy training methods. Strategy training aims at promoting cognitive strategies such as visualising, summarising, and note-taking (Klauer, 2010). In a study investigating the effectiveness of hypertext reading strategies among primary school children for comprehension (Fesel et al., 2016), participants were taught four reading strategies: planning, monitoring, evaluation, and elaboration (versus a no-strategy training control). Several learning outcomes were measured, including number of pages read, literal versus inferential reading, and knowledge representations. Participants receiving the strategy training showed better comprehension scores versus those without. The results suggest that training readers on how to evaluate information, among other skills, might facilitate hypertext comprehension. Another way readers of hypertext might be supported is by advanced user models which provide 'live' feedback as they navigate through the text. For instance, if the system detects that a student is navigating through task-irrelevant pages, then an on-screen prompt may appear to focus their attention on relevant information or suggest a more relevant link (Vidal-Abarca et al., 2014). Future technological advancements might lead to further adaptive hypertext systems which guide navigation towards goal-relevant information in reading situations where the reading goal must be reached as quickly and as efficiently as possible.

To summarise this section, there have been several methods proposed to support readers of hypertext to ensure they engage in goal-directed navigation behaviours. Research has shown a positive relationship between the presence of graphical overviews, strategy training, and comprehension, individually. In particular, low prior knowledge and low working memory readers benefit from

graphical overviews because they are the most disadvantaged when reading hypertext. Future studies should continue to explore how to facilitate hypertext reading and navigation.

3.5 Chapter Summary

The aim of this chapter was to explore navigation of hypertext. It identified and discussed the three main competencies of interactions with hypertext: navigation, integration, and evaluation. Regarding navigation, many hypertext readers experience disorientation and report difficulties in locating information and ordering it in a coherent way. Some navigational behaviours are positively related to comprehension (e.g., progressing through the text in a linear direction, spending greater time on individual pages), while others are negatively related to comprehension (e.g., making non-linear 'jumps' throughout the text, selecting hyperlinks that lead to information unrelated to current reading goal). Regarding integration, there is evidence that hypertext readers are particularly disadvantaged when answering inferential comprehension items. An explanation for this may be that navigational challenges hamper the formation of a coherent mental representation of text structure according to the situation model (Kintsch, 1988). Regarding evaluation, it is a challenge for hypertext readers to evaluate the relevance of hyperlinks so that they are able to access information related to their reading goal. Reading skill, working memory, prior knowledge, and reading strategies are all important factors for determining how individuals navigate hypertext, and this navigation is typically measured by log files. There have been several ways to facilitate navigation of hypertext proposed in the research literature, with graphical overviews being particularly promising in their effectiveness at reducing disorientation, promoting more efficient navigation, and improving comprehension.

Chapter 4: Experiment 1 – How Metacognitive Experience and Working Memory are related to Navigation across Study Media

This chapter will describe the first in a series of empirical experiments which assess how students learn from and navigate hypertext. The primary focus of this study will be to explore differences between study media and the impact of navigation, working memory, metacognition, and reading strategies on reading comprehension. The rationale for this experiment has already been described in the previous introductory chapters (see Chapters 1-3), so only new information will be presented below.

4.1 Background

4.1.1 Paper versus Screen

In educational contexts, students read for many reasons including to locate specific information, to learn, to develop deeper understanding, and to edit and proofread assessment tasks. Stoop and colleagues (2013a; 2013b) conducted two studies which investigated university students' use of print and electronic texts. Their first study found that students who accessed an electronic textbook on e-readers and laptops frequently complained of the inflexible nature of the text for annotating. Half of the students opted to print the text instead of reading it on screen, demonstrating a preference for print text learning (Stoop et al., 2013a). In the second study, various webpages were used to illustrate different information rather than text being presented on screen as a block of text to scroll through (scrolling text).

The researchers found that students' comprehension of complex information was greater from paper than it was for the digital texts (Stoop et al., 2013b). Their findings indicated that students prefer, and learn better from, information on paper versus digital texts, and choose to print out documents when possible. Despite this, there is a growing amount of evidence to suggest that students are reading less on paper and more on electronic devices (Corcoran, 2014; Giebelhausen, 2015; Hahnel et al., 2015; Neumann, 2016; Shishkovskaya et al., 2015). Therefore, it is vital that research continue to investigate the differences between paper and screen learning to support students as schools and universities move closer towards paperless classrooms.

One way in which students' learning and overall reading experience may be affected is by how digital texts are displayed. Reading text from an electronic screen has become increasingly prevalent for both recreation and education over the past few decades, with many devices able to display text such as computers and e-readers (Kong et al., 2018; Picton, 2014; Precel et al., 2009). Early studies from the 1980s showed disadvantages of reading text from screen compared to paper. For example, proofreading performance was found to be faster and more accurate on paper than on screen (Gould & Grischkowsky, 1984; Wilkinson & Robinshaw, 1987). In addition, many readers of digital texts reported eye-related symptoms including eyestrain, dry eyes, and blurred vision (Ong et al., 1981; Rey & Meyer, 1980). Most of these early studies used cathode ray tube (CRT) displays to present text. However, this technology has since become obsolete, with improved screen technology enabling users to personalise and adjust features of the display including background luminance and resolution.

A series of experiments were conducted by Köpper et al. (2016) to test whether developments in display technology would suffice to eliminate disadvantages in reading from screen versus paper. Across four experiments, they assessed proofreading speed and performance on modern thin film transistor liquid crystal displays (TFT-LCD). They found equivalence of screen and paper displays for proofreading when the TFT-LCD screens were positioned similar to the paper texts. However, digital text readers generally experienced greater eyestrain symptoms and poorer proofreading speeds even after adjusting luminance. Therefore, technological advancements in the ways in which digital text is displayed may reduce the disadvantages for simple reading tasks such as proofreading, but have not been enough to overcome other disadvantages related to reading experience compared to paper.

Further research could investigate the differences between paper and screen learning for other reading tasks, such as deep and sustained reading to comprehend and evaluate new information. Furthermore, while technological advancements have resulted in several ways for texts to be presented on screen, new types of text have also been created to be displayed on these new screens (e.g., hypertext). The present study will explore the differences between reading on paper and screen across different types of digital texts, and the impact on comprehension.

4.1.2 Hypertext

When reading to learn new information online, students may encounter a number of different types of text. One of the most common types of online text is hypertext, which is a nonsequential and nonlinear system wherein readers move from one section of text to another by clicking on 'hyperlinks.' Previous research has

found that highly structured hypertexts facilitate the development of study strategies and internal text representations (i.e., related to organisational structure and semantic relationship between text parts), which leads to better comprehension (Dee-Lucas, 2012). However, some readers, such as those with low working memory ability or low prior knowledge, may find it difficult to organise information from different sections in a coherent way, resulting in weaker comprehension (Burin et al., 2015). Research on traditional text comprehension suggests that the quality of readers' text representations depends partly on the degree to which they interrelate the text content (Kintsch, 1986; van Dijk & Kintsch, 1983). Familiar text organisations, such as the sequencing of related ideas, has been found to facilitate the development of a coherent mental text representation (Charney, 1987; Wylie & McGuiness, 2004).

Hypertext differs from traditional text in that information does not necessarily follow a chronology, and hyperlinks may take the reader to unrelated information thereby disrupting readers' development of a coherent text representation and weakening comprehension. The present study will investigate how students learn across study media, including print text, scrolling text, structured hypertext, and networked hypertext.

4.1.3 Comprehension Across Study Media

Reading comprehension, at a fundamental level, relates to the amount of information a reader can extract from a text. However, it also encompasses a set of underlying cognitive processes including phonemic awareness, letter and word identification, inference-making, activation of prior knowledge, and creating meaningful connections between text parts. Researchers may be interested in the

comprehension processes involved in reading different types of texts, and whether those processes are similar across study media. Some research has suggested that reading comprehension, as well as a range of other outcomes including engagement and overall experience, is weaker when reading on screen than on paper (Herold, 2014; Mangen & Kuiken, 2014; Mangen et al., 2019; Noyes et al., 2004). For example, one study in which primary school pupils read two texts either in print or on a computer screen found that those who read in print scored significantly better on reading comprehension tests than those in the digital condition (Mangen et al., 2013). Similarly, other studies have found that children's comprehension of informational texts was better for print than digital texts (Kerr & Symons, 2006; Verdi et al., 2014). Therefore, further investigation is required to assess the effects of print and digital text learning on comprehension.

Singer and Alexander's (2017) literature review found that there was an association between text length and comprehension performance across mediums. It revealed a greater effect of medium on comprehension when the texts being processed were longer in length. When the text involved more than 500 words, comprehension scores were significantly better for print than for digital text reading (Davis & Neitzel, 2012; Mangen et al., 2013; Mayes et al., 2001). However, a review of research exploring differences between print and digital text comprehension found that many studies used short texts of less than 1000 words (Delgado et al., 2018). As a result, future research investigating differences between print and digital text learning should make use of longer expository texts. The present study will test students' textual comprehension of a lengthy (around 2500 words) expository text presented across print and digital formats.

4.1.4 Working Memory

Working memory is the set of mental resources that individuals use to encode, activate, store, and manipulate information while they perform cognitive tasks (Baddeley, 2003). If the processing demands of a task are high, then the limited working memory stores can quickly become overburdened and comprehension compromised. In print text reading, readers usually make forward and backwards navigational decisions by turning pages. Readers' comprehension of print text is aided by spatio-temporal markers such as the tactile sensation of turning the pages of a book, including their weight and texture (Mangen et al., 2013). These markers improve memory of where information is located, as well as whether this information can be found near the beginning, middle, or end of the text which can be useful for revisiting information.

However, as readers progress through hypertext, they must remember many navigational steps as they click through hyperlinks, as well as the content of multiple sections. In addition, the notion of a beginning, middle, and end in hypertext is more abstract; information is distributed across numerous interconnected pages which can mean locating previous-read information is more difficult. According to DeStefano and LeFevre's (2007) process model of hypertext reading, the additional processing demands of readers' interactions with hyperlinks. To test this, present study will assess students' working memory and the relation to navigation and comprehension of hypertext.

4.1.5 Metacognitive Experience

Metacognition experience is highly relevant for reading because monitoring one's own behaviour is important when, for example, making the decision to read a

text more than once if one feels that comprehension was low (Furnes & Norman, 2015; Son & Metcalfe, 2000). Metacognitive activities like self-regulation and predicting one's own comprehension performance are considered to be higher-level processes. However, a review of research on metacognition and reading found that individuals generally engage more in shallow processes when reading digital texts versus print texts (Wylie et al., 2018). Therefore, one might expect digital text readers to engage in less metacognitive monitoring of their own learning, and therefore be less accurate when predicting their own performance on comprehension tasks.

Metacognitive skills such as strategizing and monitoring have been found to predict better comprehension in students reading hypertext (Schwartz et al., 2004), while others have found evidence of screen inferiority when assessing students' evaluations of their own learning, comprehension, and regulation of reading time (Ackerman & Lauterman, 2012; Ackerman & Goldsmith; Lauterman & Ackerman, 2014; Lee & Tedder, 2003; 2004). The present study will investigate students' metacognitive experience when reading from print and digital texts.

4.1.6 Hypertext Navigation

Some research has suggested that the emphasis on immediate rewards in digital media may result in difficulties engaging in more challenging tasks like deep learning and inference-making when navigating through hypertext (Annisette & Lafreniere, 2017). Furthermore, it has been proposed that readers of digital texts engage more in scanning and skimming rather than deeper engagement necessary for greater comprehension (Liu, 2005; 2012). The numerous hyperlinks and navigation decisions to be made at each node may inhibit the kind of focused, sustained

attention required to efficiently comprehend target textual information (Baron, 2017; Thain, 2018). Therefore, the present study will investigate how students navigate hypertext by analysing log-file information, and how this relates to reading comprehension performance.

4.2 Aims and Hypotheses

An experiment was conducted with the aim of investigating students' learning and navigation across study media. It sought to address the following hypotheses:

H_1: There will be higher comprehension scores in the print and scrolling text conditions than in both the structured hypertext and networked hypertext conditions.

H_2: There will be significant positive relationship between total verbal working memory scores and comprehension test scores across all reading conditions.

H_3: There will be a greater difference between hypertext readers' comprehension score predictions and their actual comprehension test scores than for print and scrolling text readers.

H_4: Hypertext readers will report more navigational difficulties (e.g., disorientation) than print and scrolling text readers.

4.3 Method

4.3.1 Design

This study made use of a between-subjects experimental design in which 54 participants were assigned to one of four reading conditions: print text (N = 13),

scrolling text; *N* = 14), structured hypertext (*N* = 13), or networked hypertext (*N* = 14). Participants read an informational text and completed questionnaires during one 60-minute testing session. The on-screen texts were designed to look like expository texts similar to those which students might encounter when engaging with digital learning resources. Participants were randomly assigned, and blinded to, their conditions. Table 4.1 gives a brief description each condition (see Chapter 1 for more detailed descriptions of different types of hypertext).

Table 4.1

Descriptions of each reading condition.

Reading Condition	**Description**
Print Text (*N* = 13)	Text printed out onto paper. All 13 sections presented in chronological order and separated by section headings.
Scrolling Text (*N* = 14)	Text appears on screen with the 13 sections presented in chronological order. Readers scroll down the block of text using either mouse wheel or scroll bar. No hyperlinks. A 'back to top' button allows reader to immediately navigate to the top/beginning of text.
Structured Hypertext (*N* = 13)	Text presented on screen with 13 individual webpages. All readers open the webpage on the first section of the text and navigate to other sections by clicking on either blue underlined hyperlinks (total = 7), or a 'next' button which takes the reader to the next main section in the chronology of information. A 'back to previous page' button allows reader to return to the previous section.
Networked Hypertext (*N* = 14)	Similar to Structured H'text, but with 17 hyperlinks which may take the reader to any section along the chronology of information (e.g. from the introduction section to the battle conclusion section).

A ‘back to previous page’ button allows reader to return to the previous section.

The graphical structures of both the structured and networked hypertext conditions can be seen in Figures 4.2 and 4.3, respectively. Within these Figures, each square represents an individual page of the website. Each arrow represents a navigation path accessed in the text via either a hyperlink or ‘next’ button. Some pages have several arrows pointing to other pages, representing when a page has multiple hyperlinks.

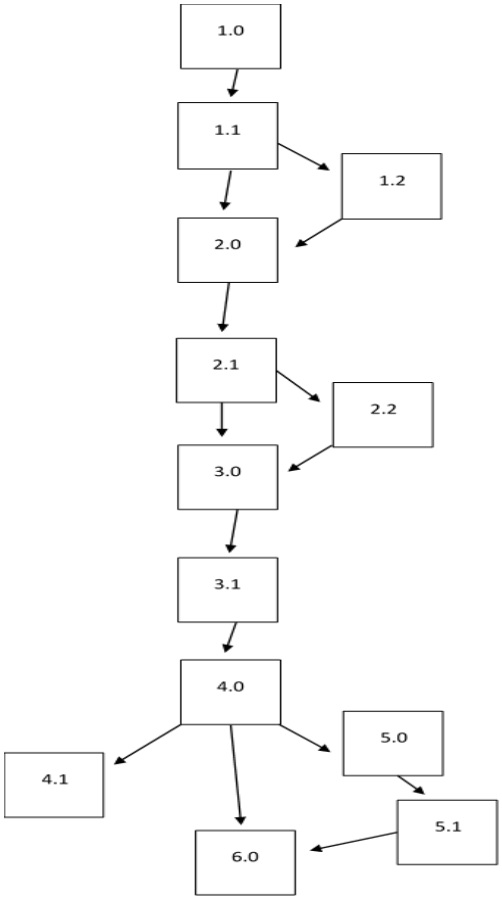


Figure 4.2. Overview of Structured Hypertext

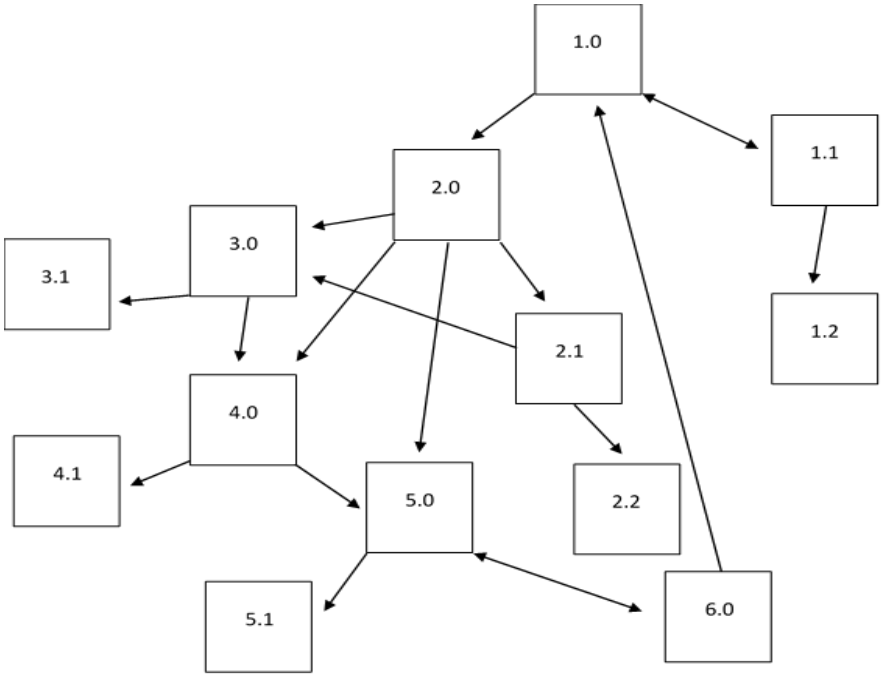


Figure 4.3. Overview of Networked Hypertext

The information necessary to correctly answer the 28 comprehension test questions can be found distributed across the 13 sections of the text. For the print and scrolling text conditions, this meant that the answers were distributed across the 13 sections separated by section headings. For instance, information to answer questions 13, 14, and 24 correctly, was located in the 'England Expects' section. In the structured and networked hypertext conditions, this meant that answers were distributed across the 13 individual pages of the websites.

4.3.2 Participants

The study consisted of a sample of 54 healthy participants all of whom were first-year psychology undergraduate students, recruited from the university campus via an online study recruitment program. There were 12 males (22.2%) and 42 females (77.8%), ranging from 18 to 26 years of age (M = 19.0, SD = 1.43). Individuals who responded to the experimenters were allocated a timeslot to

participate, and those who successfully completed the study received 60 participation credits. Participants were not subject to any exclusion criteria.

4.4 Measures and Materials

4.4.1 The Text

Each of the four reading conditions included the same informational text. Information contained within the text consisted of 3387 words based on the history of the Battle of Trafalgar edited from information gathered on the BBC History website (Appendix A). In total, there were 13 sections and 68 paragraphs, with an average of 22 words per sentence. Readability tests were conducted on the whole text to assess its suitability for the expected sample of first-year undergraduate students. Anything above the score of 30.0 is considered suitable to be read by university students (Flesch, 1948). This resulted in a Flesch-Kincaid Reading Ease score of 48.3, and a Flesch-Kincaid Grade Level of 11.8 meaning that while the text was considered 'difficult', it was suitable to be read by senior high school and university students. Analysing each page individually, there was a readability range of 47.8 (*min* = 19.0, *max* = 66.8 (see Table 4.4). A score of 19.0 is considered very difficult to read and is most suitable for university graduates, however section 4.1 is the smallest of the entire text (63 words) and contains several names and dates which may contribute to its anomalously low readability score. Therefore, all sections were suitable for the education level of the participants.

The text followed a chronology; the beginning sections described the context in which the Battle of Trafalgar was fought and introduced some of the key individuals involved before moving on to describing details of the battle itself and detailing its conclusion and consequences for those involved. It was subdivided into

13 sections, each providing new information with its own section heading. In the print text condition, the text was printed out onto paper with each section following on from each other in chronological order, separated by section headings. In the structured hypertext condition, the sections of the text were presented in chronological order and separated by section headings. In the structured and networked hypertext conditions, each of the 13 sections had its own individual page with section headings.

The sections were then given page numbers for analysis and visual representation purposes only; participants were not aware of the numbers. Pages 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 consisted of core information about the Battle of Trafalgar itself. Sections that provided extra information about relevant individuals and places were part of the chronology but did not contain information about the events of the battle itself were assigned as pages 1.1, 1.2, 2.1, 2.2, 3.1, 4.1, and 5.1. Each section had a small accompanying picture appearing on the right-hand side of the page/screen. The picture was usually a painting of something naval like a sail ship or the sea, whereas sections relating to individuals had a picture of the person themselves.

Table 4.4

Information about each page of the text, including readability statistics.

Page	Title	Hyperlinks		Word Count	Paragraphs	Lines	F-K Reading Ease	F-K Grade Level
		C2	C3					
1.0	Global Power	1	2	415	9	36	38.9	13.5
1.1	Admiral Lord Nelson	1	2	293	5	23	47.8	11.7
1.2	Admiral Lord Nelson and Lady Hamilton	0	0	495	8	39	44.9	12.1
2.0	Battle Plan	2	4	233	5	20	54.7	10.4
2.1	Admiral Pierre de Villenueve	0	1	129	3	13	39.5	12.9
2.2	Battle in the Indian Ocean	0	0	176	3	14	30.9	17.3
3.0	England Expects	1	2	265	6	22	66.8	9.3
3.1	Cape Trafalgar	0	0	113	3	10	51.6	10.6
4.0	The Battle	2	2	266	5	22	52.4	11.4
4.1	The Bucentaure	0	0	63	1	12	19.0	23.2
5.0	Nelson’s Death	0	2	266	6	21	52.5	10.0
5.1	Kiss Me Hardy	0	0	270	5	22	43.9	14.4
6.0	Cost of Victory	0	2	402	9	32	51.3	11.5

4.4.2 Reading Comprehension

Reading comprehension performance was assessed through a test consisting of 28 items. All 28 questions were textual-based, requiring the recall of specific information such as dates or names to answer both multiple-choice items with four options (n = 26) and short-answer items (n = 2). All 28 items were scored as either correct (1) or incorrect (0). Also on this questionnaire were confidence ratings, where participants indicated on a percentage scale the certainty that they had answered each of the 28 questions correctly ranging from certain they had answered it incorrectly (0%) to certain they had answered it correctly (100%).

4.4.3 Working Memory

1) The trail-making component of the Delis-Kaplan Executive Function System (DKEFS; Delis, Kaplan, & Kramer, 2001) assessed two fundamental central-executive measures of working memory: cognitive flexibility and switching ability. Participants completed two trials: connecting all of the numbers in order (number sequencing); and letter-number switching in order (set-shifting), and the time taken to complete each trial was recorded. The difference in time taken to complete the two trials was calculated to create a switch-cost score (i.e., the time cost of switching processes from number sequencing to set-shifting).

2) Verbal working memory task using names of animals. The experimenter verbalised a series of monosyllabic common animal names, which the participant then attempted to recall in order, across three trials: forwards (trial one); backwards (trial two); and in size order (trial three). The number of animals began at a length of two, and increased every two sequences up to a maximum length of nine. The trial ended when the participant got two attempts at a length incorrect. Two

measures were taken in each trial: maximum verbal span, the maximum length of animals participants were able to successfully recall at least one sequence of (*max.* = 9 in each trial, *max.* = 27, total); and raw score, the total number of sequences correctly recalled in each trial (*max.* = 16 in each trial, *max*. *total* = 48).

3) The Spatial Span component of the Wechsler Non-Verbal Scales of Ability (Wechsler & Naglieri, 2006) assessed visuospatial working memory. It involved the experimenter tapping a sequence of blocks, which participants attempted to repeat in two trials: forwards (trial one), and backwards (trial two). The number of blocks began at a length of two, and increased every two sequences up to a maximum length of nine. Two measures were taken: maximum visuospatial span, the maximum number of blocks participants were able to successfully recall at least one sequence of (*max*. = 9 in each trial, *max.* = 18 total); and raw score, the total number of sequences correctly recalled in each trial (*max.* 16 in each trial, *max.* = 32 total).

4.4.4 Prior Knowledge, Interest and Effort

Prior knowledge was assessed through a five-item prior knowledge, interest, and effort (PIE) questionnaire in which participants were asked to indicate how much they knew about, and how much interest they had in the given topic for the reading task, how many comprehension questions they predicted they would answer correctly, as well as how much effort they believed would be required of them to complete the reading task. Participants rated their knowledge on a six-point scale, with one being 'very little' and six being 'very much'. If participants indicated that they did have some prior knowledge of the topic, they were also asked which sources they had acquired it from; they were given several options including school, personal

interest, news, or other. Also rated on a six-point scale was interest, ranging from 'very uninterested' to 'very interested', and effort, ranging from 'very little effort' to 'a lot of effort'.

The PIEpre questionnaire also included an item which asked how many questions participants believed they would be able to answer correctly, given four multiple-choice options, out of a total of 28. This measured overall *prediction of performance* (PoP). The PIE questionnaire had both a pre-test (PIEpre) and post-test (PIEpost) version. The four-item PIEpost was administered after the reading task and comprehension test had been completed and asked similar questions to the PIEpre, participants now having read the text. It asked how much they now know about the topic, how many comprehension questions they predict they answered correctly, their interest in the topic, and how much effort was required to answer the test questions correctly.

4.4.5 Metacognition

A *judgements of learning* (JoLs) questionnaire assessed how participants evaluated their own learning. This was administered after they had read the text, but before they answered the comprehension test questions. Participants indicated on a percentage scale the certainty that they would be able to identify the correct response given four options for each of the 28 questions, with 0% being certain they would answer it incorrectly, and 100% being certain they would answer it correctly. The percentage scale included dashes to represent percentage points and numbers at each 10% point on the line (10%, 20%, 30%, etc.). The 28 confidence ratings that participants gave for each question on the comprehension test formed part of the metacognitive assessment.

4.4.6 Reading Strategies

The self-reported reading strategies used by participants while navigating through the text were identified via a questionnaire adapted from one used in Anmarkrud & Braten's (2009) reading study. Participants responded to 12 items on a 10-point scale ranging from 'never' to 'very often/always'. Items included statements such as, 'I tried to find connections between the different parts of the text', 'I tried to make all of the content fit together', and 'I tried to memorise what I thought was important'.

4.5 Procedure

1) Participants responded to the study advert on the university's online participation system and signed up to an available timeslot. After arriving in the test lab, participants read through the study information sheet and were invited to provide their informed consent.

2) Participants were asked to complete the trail-making, verbal, and visuospatial working memory tasks taking approximately 20 minutes. Next, they completed the PIEpre questionnaire which lasted around 2 minutes.

3) Participants were then randomly assigned to one of four reading conditions: print text, scrolling text, structured hypertext, or networked hypertext. They were told that they would have 20 minutes to read the information, and that they would be asked 28 questions about the text in a test afterwards. Using PC logging software, navigation information was recorded. This included the amount of time participants spent on each section/page, the order in which they progressed through the information in the two hypertext conditions, and the number of 'clicks'

each participant executed. This was recorded to identify whether their reported navigation behaviours (assessed via the reading strategies questionnaire) were aligned with their actual behaviours. Participants were not aware during the reading task that their navigation behaviour was being recorded.

4) Following the completion of the reading task, participants completed the remaining questionnaires which took approximately 20 minutes to complete. They completed the JoL questionnaire, comprehension test (with confidence ratings), the PIEpost questionnaire, and the reading strategies questionnaire. Finally, participants were invited to read and sign the debrief form, and there was an opportunity at the end of the test session for them to ask any questions about the experiment.

4.6 Results

This section will report the results of the present experiment. Reading comprehension results will be reported first, followed by working memory, metacognition, PIE, reading strategies, and navigation measures.

4.6.1 Reading Comprehension

All 28 reading comprehension items were scored as either correct (1) or incorrect (0) for a maximum score of 28. Overall, the test scores ranged from 7 to 25 with a mean of 18.13. The greatest range of scores was found in the print text condition, wherein the lowest score was 7 and the highest score was 21. Participants performed best when they read scrolling text. These data are shown in Table 4.5. Reliability analyses of the reading comprehension test questions showed a sufficient Cronbach's alpha (α = .74).

A one-way between subjects ANOVA conducted to assess the effect of reading condition on comprehension test scores showed no significant main effect of reading condition on comprehension test scores, $F(3, 54) = .406$, $p = .750$, partial $\eta^2 = .024$. Challenging **H_1**, participants' test scores did not significantly differ between the reading conditions of print text, scrolling text, structured hypertext, or networked hypertext and the hypothesis was rejected.

Table 4.5

Comprehension scores across each group.

Condition	*M*	*SD*	*Range (min. – max. score)*
Overall	18.11	4.14	18 (7-25)
Print Text	17.08	4.84	14 (7-21)
Scrolling Text	18.71	4.60	13 (12-25)
Structured H'text	18.23	3.72	13 (10-23)
Networked H'text	18.36	3.59	13 (12-25)

4.6.2 Working Memory

Analyses were conducted to test the relationships between working memory and comprehension across study media. The hypothesis **H_2** predicted that low working memory ability readers would be disadvantaged in hypertext. Since there was a significant positive correlation between verbal span and raw scores, $r(54) = .793$, $p < .001$, and visuospatial span and raw scores, $r(54) = .885$, $p < .001$, only verbal and visuospatial raw scores will be reported.

Switching Ability

Performance on the trail-making task is shown in Table 4.6. Overall, there was a mean completion time of 20.91 seconds for trial one, and 79.18 seconds for trial two. There was no significant difference in total completion time between groups for either the number sequencing, $F(3, 54) = .381$, $p = .767$, partial $\eta^2 = .022$, or set-shifting trials, $F(3, 54) = .303$, $p = .823$, partial $\eta^2 = .018$. Switch-cost scores were calculated (the higher the value, the greater the cost of switching between processing tasks), and there was no significant difference between groups, $F(3, 50) = .302$, $p = .823$, partial $\eta^2 = .018$.

Table 4.6

Performance on each trial of the trail-making task and switch-cost scores across each group.

Trial	Print		Scrolling		S. H'text		N. H'text	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sequencing	10.39	4.14	20.86	5.96	19.92	7.22	22.37	7.51
Set-Shifting	51.70	27.06	51.88	18.17	45.21	18.83	50.27	21.13
Switch-Cost	31.31	24.84	31.02	18.73	25.30	11.55	27.90	17.88

Note. S. H'text = Structured Hypertext; N. Hypertext = Networked Hypertext.

Pearson's correlations tested the relationships between both trials, switch-cost, and comprehension across each condition, finding no significant correlations (Table 4.7). There were also no significant correlations for each group separately.

Table 4.7

Correlations between both trials of the trail-making task, switch-cost scores, and comprehension.

Trial	*r*	*p*
Sequencing	.013	.927
Set-Shifting	-.107	.439
Switch-Cost	-.122	.380

Verbal Working Memory

Performance on the verbal working memory test was best for forwards order (M = 7.94, SD = 3.18), and weakest for reverse order (M = 5.04, SD = 1.54). There were no significant differences in verbal working memory scores between text conditions, $F(3, 50) = 1.85$, $p = .150$, partial $\eta^2 = .452$ (Table 4.8).

Table 4.8

Descriptive statistics for each trial of verbal working memory test across each group.

Trial	Print		Scrolling		S. H'text		N. H'text	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall	19.00	3.54	20.64	3.27	19.54	2.70	17.93	2.84
Forwards	8.00	1.29	8.21	1.37	8.08	1.32	7.50	1.34
Reverse	5.00	1.73	5.36	1.74	5.15	1.28	4.64	1.45
Sequencing	5.92	1.55	6.57	1.22	6.31	1.11	5.86	1.35

In support of **H2**, Pearson's correlations found a significant positive relationship between total verbal working memory scores and test scores across all reading conditions, $r(54) = .376$, $p = .005$, meaning the greater participants' working verbal memory score, the higher they scored on the reading comprehension test (Figure 4.9).

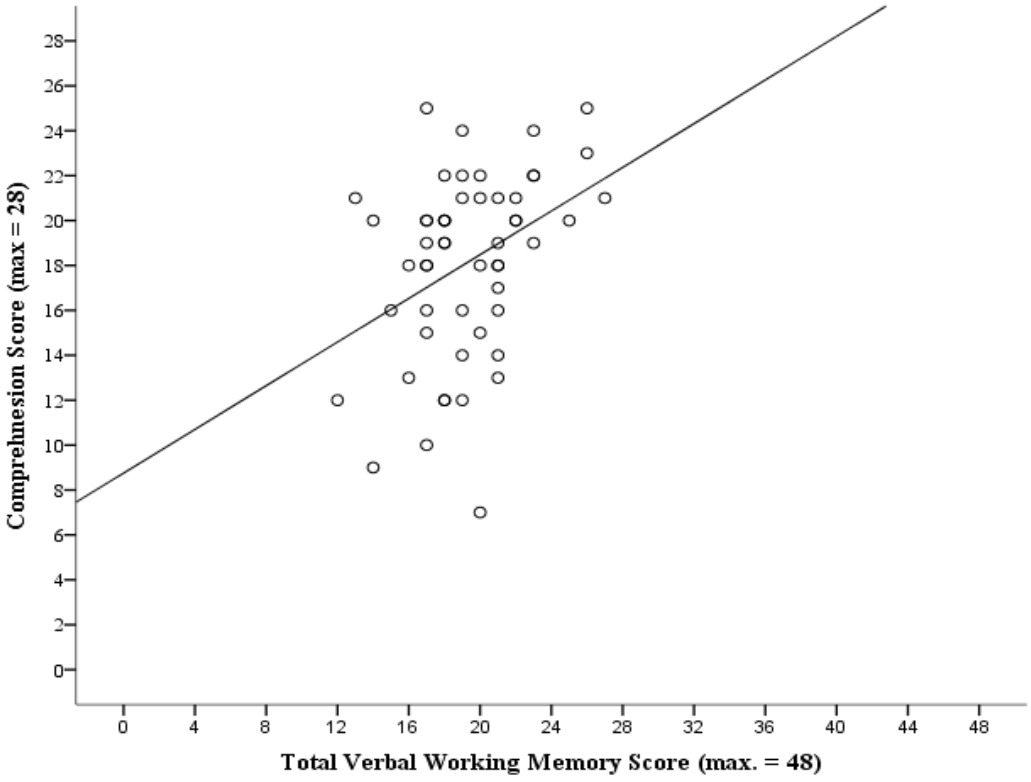


Figure 4.9. Correlation between comprehension test scores and total verbal working memory scores across all participants.

Additional correlations assessed the relationship between verbal working memory and comprehension for each group separately, finding the only group in which participants' verbal working memory was significantly correlated with comprehension was for those in the scrolling text condition, $r(14), = .621$, $p = .018$ (Table 4.10).

Table 4.10

Correlations between verbal working memory and comprehension across each group.

Condition	*N*	*r*	*p*
Print Text	13	.263	.385
Scrolling Text	14	.621	**.018***
Structured H'text	13	.443	.129
Networked H'text	14	.154	.600

***** significant to $p < .05$.

Visuospatial Working Memory

Performance on the visuospatial working memory test was best for forwards order (M = 7.98, SD = 1.68), and weakest for reverse order (M = 7.31, SD = 1.70). There were no significant differences between groups for visuospatial scores between groups, $F(3, 50) = 1.58$, $p = .207$, partial $\eta^2 = .086$ (Table 4.11).

Table 4.11

Descriptive statistics for each trial of visuospatial working memory test across each group.

Trial	Print		Scrolling		S. H'text		N. H'text	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall	15.54	2.33	15.36	3.30	16.54	2.82	13.86	2.67
Forwards	8.38	1.12	7.93	2.02	8.46	1.61	7.21	1.67
Reverse	7.15	1.68	7.43	1.87	8.08	1.80	6.64	1.28

Challenging **H_2**, Pearson's correlations found no significant relationship between visuospatial working memory and comprehension scores, $r(54) = -.160$, $p = .247$. Additional correlations which assessed the relationship between visuospatial working memory and comprehension for each group separately found no significant correlations in any of the groups (Table 4.12).

Table 4.12

Correlations between visuospatial working memory and comprehension across each group.

Condition	*r*	*p*
Print Text	-.299	.320
Scrolling Text	-.175	.548
Structured H'text	-.005	.987
Networked H'text	-.156	.595

To summarise the results for working memory, there was no relationship between switching ability and comprehension, but there was a positive relationship between verbal working memory and comprehension overall. However, when looking at each group separately, scrolling text was the only group in which participants' verbal working memory was correlated with their comprehension scores. No relationships were found for visuospatial working memory and comprehension.

4.6.3 Metacognition

JoL Ratings. Taking the average of all JoL ratings for each condition, participants in the networked hypertext reading condition generally gave lower

certainty ratings (M = 48, SD = .16) compared to the scrolling text (M = 55, SD = .20), structured hypertext (M = 54, SD = .14), and print text (M = 54, SD = .13) conditions. A MANOVA found no differences in JoL ratings between groups, $F(84, 75) = .961$, $p = .571$, partial $\eta^2 = .518$.

Confidence Ratings. Each of the 28 JoL ratings were highly correlated with the confidence ratings (CR), meaning that answering the questions in the comprehension test did not affect the level of certainty participants had that they answered correctly. The average confidence ratings for each condition were calculated, and the same pattern as the JoL ratings was found; that those in the networked hypertext reading condition generally gave lower certainty ratings (M = .53, SD = .17) compared to the scrolling text (M = .64, SD = .17), structured hypertext (M = .59, SD = .17), and print text (M = .59, SD = .17) conditions. A MANOVA found that there were no differences in confidence ratings between groups, $F(84, 75) = 1.24$, $p = .176$, partial $\eta^2 = .580$.

The average JoL and confidence ratings for each reading condition were compared with participants' actual comprehension performance, finding that JoL and CR ratings were lower than actual comprehension scores across each condition, indicating underconfidence (Figure 4.13). In support of **H3**, the largest discrepancy between both JoL (17%) and CR scores (12%) and actual comprehension scores was in the networked hypertext condition, indicating that participants in this condition were the least accurate at evaluating their comprehension performance compared to other groups, $t(4) = 38.286$, $p < .001$.

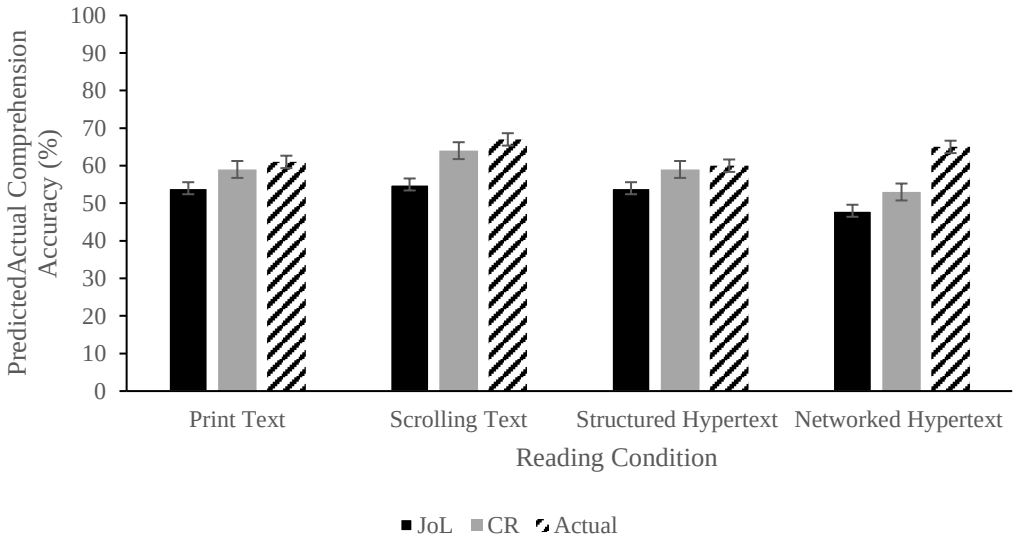


Figure 4.13. Average JoL and confidence ratings compared with actual performance accuracy across each group.

4.6.4 Prior Knowledge, Interest, and Effort (PIE)

Before taking part in the reading task, participants first completed the PIEpre questionnaire, in which they were asked to rate on a six-point scale their prior knowledge of the Battle of Trafalgar (*M* = 1.20, *SD* = .53), their interest in the topic (*M* = 2.43, *SD* = 1.13), and rate how effortful they believed answering the questions would be (*M* = 4.44, *SD* = 1.00). They predicted that they would be able to answer less than half of all questions (*M* = 13.67, *SD* = 4.18). The descriptive statistics for the PIEpre and PIEpost questionnaires across all conditions are displayed in Table 4.14.

Table 4.14

Descriptive statistics for PIEpre and PIEpost measures across each group.

Measure	Pre/Post	Reading Condition							
		Print		Scrolling		S. H'text		N. H'text	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
PK (1-6)	Pre	1.23	.44	1.07	.27	1.23	.44	1.29	.83
	Post	2.77	1.09	3.00	.88	2.85	.99	2.64	.93
I (1-6)	Pre	2.54	1.39	2.50	.94	2.08	.95	2.57	1.22
	Post	2.62	1.40	2.43	1.34	2.39	1.45	2.50	1.40
E (1-6)	Pre	4.46	1.23	4.71	.83	4.30	1.11	4.29	.99
	Post	4.23	1.30	4.14	1.46	3.54	.88	3.57	1.09
P (0-28)	Pre	14.31	3.52	13.57	3.78	13.46	5.01	13.36	4.68
	Post	13.46	4.94	13.93	6.18	14.38	4.15	12.50	5.24

Note. **PK** = Knowledge; **I** = Interest; **E** = Effort; **P** = Prediction.

Pearson's correlations revealed that, overall, participants' pre-test predictions were not related to their final comprehension test scores, $r(54) = .175$, $p = .206$, whereas their post-test predictions were significantly correlated, $r(54) = .638$, $p < .001$, indicating that participants were generally inaccurate at predicting how many questions they would answer correctly before they began the reading task, but accurate after they had completed it. Further correlations were conducted to assess the relationship between pre-test and post-test predictions and actual comprehension performance (Table 4.15).

In addition, ANOVAs conducted to assess whether there was an effect of reading condition on pre and post-test predictions, found no significant main effect

of reading condition on pre-test, $F(3, 50) = .133$, $p = .940$, partial $\eta^2 = .008$, or post-test predictions, $F(3, 50) = .372$, $p = .806$, partial $\eta^2 = .019$.

Table 4.15

Correlations for pre-test predictions and post-test comprehension score predictions with actual score for each group.

Predictions	Condition							
	Print		Scrolling		S. H'text		N. H'text	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Pre-test	.395	.182	.201	.492	-.122	.690	.326	.255
Post-test	**.587**	**.035***	**.700**	**.005***	**.635**	**.020***	**.697**	**.006***

***** significant at $p < .05$.

A series of t-tests were conducted for PIEpre and PIEpost questionnaire measures of knowledge, interest, and effort, to assess whether participants' ratings had either increased or decreased from before they completed the reading task and comprehension questions to after they had done so. They found that, overall, there was a significant increase in participants' knowledge of the topic from pre-test ($M = .120$, $SD = .53$), to post-test ($M = 2.81$, $SD = .95$), $t(54) = -11.64$, $p < .001$, an increase in participants' interest from pre-test ($M = 2.43$, $SD = 1.13$) to post-test ($M = 3.33$, 1.49), $t(54) = -5.04$, $p < .001$, and a decrease in the amount of effort participants predicted would be required to answer the comprehension questions pre-test ($M = 4.44$, $SD = 1.00$) to the amount of effort they reported post-test ($M = 3.87$, $SD = 1.21$), $t(54) = 3.08$, $p = .003$.

4.6.5 Reading Strategies

A one-way between subjects MANOVA which assessed whether there were any differences between groups on responses to the 12 statements in the reading strategies questionnaire found no significant main effect of text condition on responses, $F(36, 123) = 1.25$, $p = .182$. The most preferred strategies were to, 'memorise what I thought was important' ($M = 7.87$, $SD = 1.55$) and to 'try to create an overview of all the content of the text' ($M = 7.69$, $SD = 1.78$). The least preferred strategies were to 'try to imagine new situations in which the words or ideas might fit' ($M = 3.35$, $SD = 2.40$), and 'asked myself questions about the context of the text' ($M = 5.00$, $SD = 2.65$). Table 4.16 shows the average scores for each of the 12 items across all conditions.

Table 4.16

Overall scores for each of the 12 reading strategies questionnaire items, in order of mean scores.

Question Number	Description	*M*	*SD*
9	'Memorise important'	7.87	1.55
7	'Overview'	7.69	1.78
8	'Relating content'	6.94	2.11
11	'Think and repeat'	6.81	2.76
6	'Already learned'	6.39	2.62
3	'Fit together'	6.39	2.09
1	'Connections'	6.13	2.21
4	'Summarised'	5.83	2.66
12	'Meaning'	5.72	2.54
10	'Practiced'	5.43	2.81
2	'Context'	5.00	2.65
5	'New situations'	3.35	2.40

4.6.6 Navigation Behaviour

Analyses were conducted to test whether there were differences in navigation between structured and networked hypertext in navigation. The hypothesis **H_4** predicted that hypertext readers would report greater navigational difficulties (e.g., disorientation) than other groups.

Average Time Spent Per Page

A one-way between subjects ANOVA assessed whether there was an effect of hypertext condition on average time spent per page, finding that participants in the structured hypertext condition spent a significantly greater average amount of time per page than those in the networked hypertext condition, $F(1, 25) = 15.29$, $p = .001$, partial $\eta^2 = .379$ (Table 4.17).

Table 4.17

Average time spent (seconds) per page in hypertext reading conditions.

Hypertext Condition	*N*	Average Time Spent (*seconds*)	
		M	*SD*
Structured	13	160.15	36.23
Networked	14	112.57	16.28
Overall	27	135.48	39.23

'Clicking' Behaviour

The number of 'clicks' participants made during the reading task was captured. A one-way ANOVA found no significant main effect of hypertext condition on number of clicks, $F(1, 25) = .298$, $p = .590$, partial $\eta^2 = .012$, meaning those in the structured and networked hypertext conditions made a similar number of clicks (Table 4.18).

Table 4.17

Average number of clicks made by structured and networked hypertext readers.

Hypertext Condition	*N*	Average Number of Clicks	
		M	*SD*
Structured	13	30.92	22.47
Networked	14	35.14	15.17
Overall	27	33.11	19.80

Page Visits

The overall number of page visits was measured by summing the number of times each participant in the structured and networked hypertext conditions visited each one of the 13 pages of the text during the reading task. Participants visited pages 2.0 (M = 5.89, SD = 3.77) and 1.0 (M = 4.93, SD = 3.23) the most, and visited pages 2.2 (M = .59, SD = 1.08) and 5.1 (M = .70, SD = .82) the least. Pages 1.0 and 2.0 appeared early in the chronology of information, whereas pages 2.2 and 5.1 could only be accessed by clicking on hyperlinks (rather than 'next page' buttons), and appeared later in the chronology.

Participants in the structured hypertext condition made a significantly greater number of visits than those in the networked hypertext condition to page 3.1, $F(1, 25) = 17.52$, $p < .001$, partial $\eta^2 = .412$, and those in the networked hypertext condition made significantly more visits to page 5.0, $F(1, 25) = 20.27$, $p < .001$, partial $\eta^2 = .448$ (Table 4.19).

Table 4.19

Average number of visits per page for hypertext readers, with ANOVA results.

Page Number	Hypertext Condition	Average Number of Visits		*p*
		M	*SD*	
1.0	Structured	3.77	2.05	.072
	Networked	6.00	3.80	
1.1	Structured	4.62	2.92	.075
	Networked	2.86	2.60	
1.2	Structured	.69	1.32	.824
	Networked	.79	.80	
2.0	Structured	5.23	3.77	.392
	Networked	6.50	3.80	
2.1	Structured	.62	1.19	.181
	Networked	1.29	1.33	
2.2	Structured	.62	1.45	.919
	Networked	.57	.65	
3.0	Structured	4.00	2.24	.830
	Networked	3.79	2.49	
3.1	Structured	4.00	2.24	**< .001***
	Networked	1.29	.91	
4.0	Structured	3.92	2.40	.995
	Networked	3.93	2.30	
4.1	Structured	.46	1.20	.065
	Networked	1.21	.80	
5.0	Structured	.77	1.92	**<.001***
	Networked	4.21	2.04	

Page Number	Hypertext Condition	Average Number of Visits		*p*
		M	*SD*	
5.1	Structured	.38	.96	.050
	Networked	1.00	.55	
6.0	Structured	1.85	1.57	.800
	Networked	1.71	1.07	

* significant at $p < .05$.

Unvisited Pages

Inspection of the log-files revealed that there was a high proportion of participants who failed to visit an individual page at least once in both the structured and networked hypertext conditions. Only two participants visited all pages at least once in the structured hypertext condition, with four participants visiting all pages at least once in the networked hypertext condition.

Figure 4.20 shows the distribution of the most frequently visited pages in the structured and networked hypertext conditions. The percentage of participants who visited each page is represented by a percentage of shade from black (0%) to white (100%), with black pages being those which were visited by none of the participants (0% visited), and white being pages which were visited by all of the participants (100% visited). Pages containing lighter shades of grey were visited by a higher percentage of participants than those containing darker shades of grey.

Structured Hypertext **Networked Hypertext**

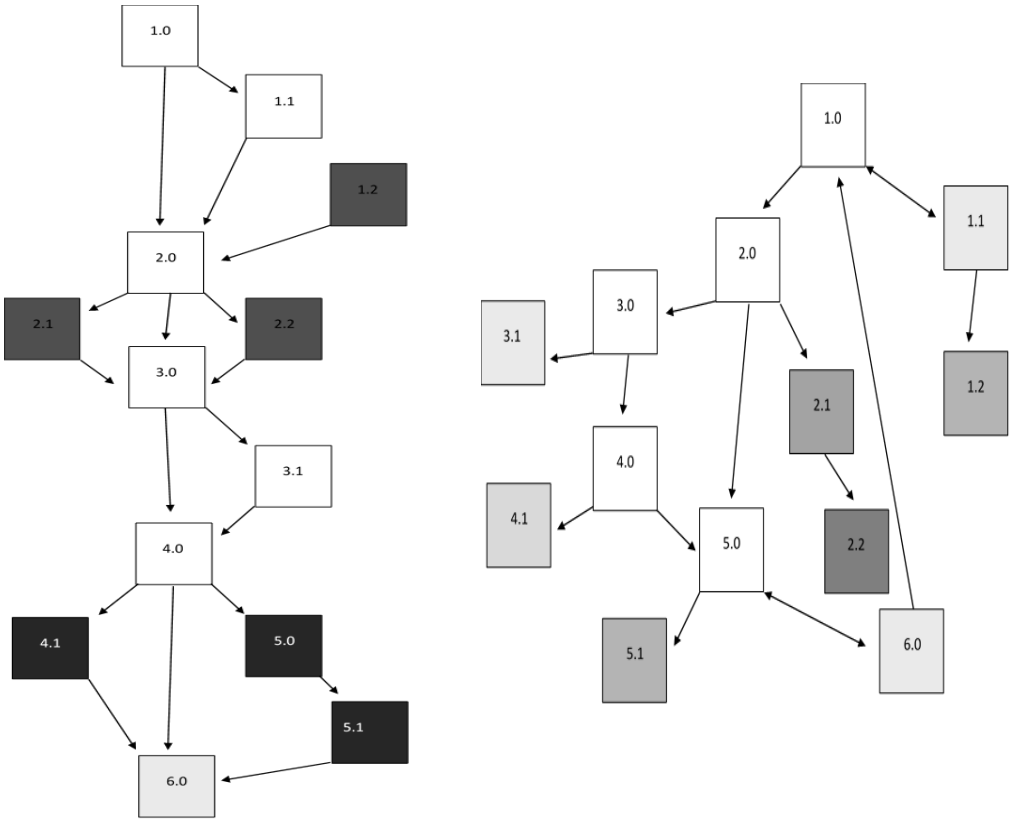


Figure 4.20. Distribution of visited pages in the structured and networked hypertext groups.

Navigation Styles

Table 4.21 shows an overview of the strongest and weakest performers in each hypertext group including an interpretation of whether their navigation activities were beneficial for comprehension. Overall, readers spent an average of 135.29 seconds per page, made 34 clicks, and scored 18 out of 28 on the reading comprehension test. Because of the high number of unvisited pages by those with the lowest comprehension scores, descriptions of their navigation behaviour are based on the pages they did visit during the reading task.

Table 4.21

Overview of strongest and weakest hypertext comprehension test performers.

Hypertext Condition	Performance	Score	Clicks	Secs. Per Page	Navigation Summary	Interpretation
Structured Hypertext	Highest	23	25	63	- Spent first 5 minutes visiting multiple pages before returning to the first page. - Revisited pages with multiple hyperlinks to click the one they had not interacted with during first visit.	- Review period to revisit pages beneficial for comprehension in structured hypertext.
	Lowest	10	28	144	- Spent first half of reading time on 7 pages and did not revisit any pages. - Second half of reading time spent making many clicks and spending short amount of time on each page.	- Spending short amount of time on pages disadvantageous for comprehension. - Poor time management – no time left after reading the final page to revisit pages for review period.
Networked Hypertext	Highest	25	37	91	- Reader made multiple ‘back to previous page’ clicks to interact with all hyperlinks. - Had visited all pages within first 10 minutes.	- Initial familiarisation period beneficial for comprehension. - Good time management - spent longest time on pages with most information, and

Hypertext Condition	Performance	Score	Clicks	Secs. Per Page	Navigation Summary	Interpretation
						shortest time on pages with least information.
	Lowest	12	22	114	- No page revisits until 5 minutes reading time remaining. - Short pages revisits meant information was missed.	- Pages were missed because reader did not revisit pages where there were multiple hyperlinks

4.7 Discussion

The present study investigated the differences between print and digital text learning by measuring the comprehension, working memory, and metacognitive experience of readers of print text, scrolling text, structured hypertext, and networked hypertext. It also explored the navigation behaviours of hypertext readers. The main findings related to these measures will be discussed. In addition, potential methodological limitations will be considered and directions for future research in this area will be recommended. Table 4.22 shows a brief summary of the main findings of this experiment.

Table 4.22

Study 1 results summary.

Variable	Key Findings
Reading Comprehension	- No main effect of text condition (print, scrolling, structured and networked hypertext) on comprehension scores.
Metacognition	- Underconfidence of performance across all groups. - Networked hypertext readers most inaccurate at evaluating their own comprehension.
Working Memory	- Verbal working memory positively correlated with comprehension scores.
Predictions, Interest, Engagement	- Comprehension predictions lower than actual comprehension scores at pre-test, but accurate at post-test. - Knowledge and interest in the text topic increased from pre-test to post-test measures, while effort decreased
Reading Strategies	- Participants in each condition reported similar reading strategies. - Most preferred strategy was to try and create an overview of all the content, whereas least preferred was to try and imagine new situations in which the words or ideas might fit
Navigation	- Networked hypertext readers reported more disorientation. - Familiarisation and review periods beneficial for comprehension

4.7.1 Comprehension Across Study Media

The findings from this study contributed to the 'paper versus screen' debate. It was hypothesised that there would be a significant effect of text condition on comprehension. Print text readers were predicted to have the highest comprehension performance than those reading from the three digital text formats (scrolling text, structured hypertext, networked hypertext). In addition, hypertext readers were predicted to have weaker comprehension than those reading print text and scrolling text. However, the present study found little support for screen inferiority; there was equivalence of performance in readers of different types of print and digital text. Participants answered over half of all comprehension items correctly across all conditions, and performance was best (albeit marginally) in the scrolling text condition.

An explanation for this may be that the comprehension test was comprised of textual items which did not require the reader to demonstrate a deeper understanding of the text (e.g., by evaluating information or forming an opinion). Inferential items measure deeper levels of comprehension, including how well the reader is able to integrate prior knowledge, make inferences based on separate sections of the text, and engage in critical analysis to assess the validity and relevance of information (Wolf & Barzillai, 2009). Some studies suggest that deeper comprehension may be impaired in readers of hypertext because of the additional processing demands of hyperlink selection and the incoherence caused by the presentation of non-linear information (Amadieu et al., 2017; Blom et al., 2018; Lee & Tedder, 2003; Salmerón, et al., 2017).

Therefore, differences in comprehension between media may only be present when both textual and inferential comprehension are assessed. In addition, others have found differences for print and digital text learning only when readers are under greater study time pressure (Ackerman & Goldsmith, 2011). In the present study, all participants had a set limit of 20 minutes reading time and study time pressure was not considered. The additional processing demands of hyperlink selection may overburden working memory resources, resulting in poorer self-regulation of study time. When study time is limited, readers of hypertext may find it difficult to locate previously read information due to the highly interconnected and complex nature of this format. Readers of print text have physical cues of chronology to help them locate target information. For example, they may wish to build a greater comprehension of the information they read near the beginning of the text; this can easily be accessed by turning pages from left to right. Future research could use a range of comprehension measures to assess both shallow and deep understanding across print and digital texts, and investigate how time pressure relates to comprehension and navigation across media.

4.7.2 Role of Working Memory

The limited stores of working memory can quickly become overburdened by the additional demands of processing the unique features of hypertext such as hyperlinks (DeStefano & LeFevre, 2007). Therefore, it was predicted that hypertext readers with lower working memory ability would be especially disadvantaged, and that there would be an effect of working memory on how well students learn across all reading conditions. In addition, lower working memory ability hypertext readers were predicted to have weaker comprehension performance than lower working memory ability print and scrolling text readers.

While the present experiment found a significant positive correlation between verbal working memory and comprehension scores across each text condition (i.e., not just in hypertext), hypertext readers with lower verbal working memory ability had the weakest comprehension scores when compared with each group (although these scores were not significantly lower). A possible explanation for these results may be that textual comprehension questions are not very effortful, and do not require deeper levels of comprehension such as inferencing and integrating. Therefore, future research could explore the effect of working memory when learning from hypertext on a range of textual and integration comprehension measures.

4.7.3 Metacognitive Experience

Other researchers have found evidence for screen inferiority in students evaluating their own learning of hypertext (Ackerman & Goldsmith, 2012; Ackerman & Lauterman, 2012; Lauterman & Ackerman, 2014). It was hypothesised that hypertext readers would be more inaccurate when predicting their performance on a reading comprehension test than those reading print and scrolling text. In the present experiment, no significant effects were found when analysing the relation between comprehension predictions and achieved scores across the four text conditions. However, hypertext readers were the least accurate at predicting and evaluating their own performance. An explanation for this could be that the added cognitive load of reading hypertext may overburden working memory's limited stores, inhibiting higher level comprehension processes like metacognitive monitoring and updating of knowledge.

4.7.4 Individual Differences in Navigation Behaviour

The C-I model emphasises the importance of being able to build a coherent mental representation of a text. In print text, the structure and chronology of a text is easily identifiable; for example, information in Western books typically reads from left to right, guiding the reader from beginning, middle, to end. Conversely, hypertext is non-linear and non-sequential, meaning that readers may find it difficult to identify the organisational structure of the text and maintain coherence. This may be especially difficult, as the executive cognitive processes involved in building a mental map of where information is located are constantly being disrupted by the presence of hyperlinks.

The reading comprehension results suggest that hypertext readers may perform as well as print text readers for the textual comprehension. However, these results reveal little about hypertext readers' navigation behaviour; how they used the reading time, what information they accessed, and in what order. The relationship between strategy use and comprehension of hypertext has been widely reported (Barab et al., 1997; Salmerón & García, 2011; Salmerón, Kintsch, et al., 2010; Shang, 2016; Trabasso & Magliano, 1996). Lawless and Kulikowich's (1996; 1998) influential studies explored the navigational profiles of hypertext users, and identified knowledge seekers, feature explorers, and apathetic users as the most common. Based on this, the present experiment predicted that strategic and knowledge-seeking navigational behaviours would be related to greater comprehension than non-strategic and feature-seeking behaviours.

Analysis of the log-files found that readers of the most complex type of hypertext, networked hypertext, visited more pages and spent less time on average per page than those reading structured hypertext, both of which have been associated with weaker comprehension (Blom et al., 2018). The networked hypertext contained

a greater number of hyperlinks and connections between pages. Networked hypertext readers may have made more visits to pages because they were trying to work out the structure of the text and how the information was connected. Others have found that students have difficulty navigating hypertext due to its complex structure (Bayazit et al., 2018; Cangoz & Altun, 2012; Shapiro & Niederhauser, 2004). Readers attempt to construct a coherent mental representation of the text by identifying connections between information parts. When a text is inherently incoherent, readers must recruit extra cognitive resources to establish and maintain a representation of structure. The findings that participants spent less time per page and made more visits in the most complex type of hypertext may be evidence that students attempted to improve coherence by findings their way around the text and identifying connections.

Participants with the highest comprehension test scores across both types of hypertext showed evidence of strategic navigation (Table 4.20). For example, these readers made several revisits to previously read pages, and took time at the beginning of their reading time to familiarise themselves with how the pages were connected and what information is included on each one. Conversely, those with the lowest comprehension test scores did not make many revisits to previously read pages and spent several periods during the reading time clicking between a few pages and spending only a few seconds at a time on each one. Therefore, strategic and knowledge-seeking navigational behaviours may be more advantageous for comprehending hypertext than non-strategic navigation.

Log-files also revealed that both structured and networked hypertext readers failed to visit several pages. One explanation for this could be that some hypertext readers did not have a clear navigation strategy. Previous research has suggested

that a range of readers (children, undergraduates, and educated adults), especially those with low working memory ability and prior knowledge, may find it difficult to apply learned strategies to reading hypertext (Amadieu et al., 2009; Naumann et al., 2008; Salmerón & García, 2011). This may be because the lack of a coherent structure in hypertext makes it difficult to form a cohesive mental representation and knowledge base of the text, something which is considered to be easier to do when reading print texts (DeStefano & LeFevre, 2007).

Due to the variability in the ways in which students navigate hypertext and the high number of unvisited pages found in the present study, future research could investigate ways of improving navigation and learning. Some examples of ways to do this are by improving annotation functions and introducing graphical overviews to facilitate navigation and the construction of a coherent mental representation of the text. Another way would be to inform readers as part of the task instructions that all information is relevant. Therefore, the second experiment in this thesis (Chapter 5) will inform participants that the comprehension test may include items related to related to any of the text, to minimise the number of unvisited pages.

4.7.5 Implications and Directions for Future Research

The findings of this experiment offer an optimistic view of the future of digital reading. When recalling information from a text (i.e., textual comprehension), this study suggests an equivalence between print and hypertext for students. However, the results also indicate that networked hypertext readers (particularly those with low verbal working memory ability), may be more inaccurate at judging their own performance than print text readers. Being able to accurately evaluate one's own learning during a reading task is important because an

individual may decide (potentially incorrectly) that they have gained enough information in one section of a text, so decide to move on to another.

The results from studies exploring the differences between print and screen learning may lead to recommendations about the type of texts readers should have access to in the future. For example, Durant and Horava's (2015) paper examined the implications of the shift from print to digital reading. They explored how academic libraries in particular could approach the digital age to ensure that print and digital media are regarded as complementary rather than interchangeable (i.e., by viewing them as serving different reading needs). They highlighted the importance of deep reading skills to facilitate analysis of information (e.g., inferring, integrating prior knowledge, evaluating). The researchers suggested that increasingly reading from screens affects the ability for critical thought and concentration amongst students, meaning that academic libraries should continue to offer paper copies of complex documents where deep reading skills are required (or ensure licensing enables the printing of these documents).

This experiment also contributed to research exploring students' preferences of reading paper or screen texts. User preference has consistently been shown to predict reader satisfaction and engagement with new information (Dillon, 1992; Merga, 2014; Rojeski, 2012). The present study found that almost all participants reported a preference for learning new information from traditional printed text sources such as textbooks. This supports others' findings that students tend to report that they learn better from printed texts (Jeong, 2010; Tveit & Mangen, 2014) and prefer to print out texts rather than read on screen (Stoop, et al., 2013a). For instance, Merga's (2015) review of studies investigating medium preference found

that very few adolescents reported they would choose to read an electronic book over a paper book.

A potential limitation of the sample used in this study is that participants' previous educational experiences were not considered, including how much prior knowledge of the text topic they had at the time of the experiment. At the time of the experiment, all that was known of the participants is that they had been accepted to study a Psychology degree at university. All participants were considered to have low prior knowledge of the text topic, but the potential variability in their route to university (e.g., A-level, leaving certificate, access courses), may have influenced performance. However, this risk was mitigated by asking participants how much knowledge they had of the text topic before taking part in the reading task. Studies primarily investigating the effect of prior knowledge on comprehension and navigation of hypertext should consider including a topic familiarity questionnaire to help control for participants' previous experience and knowledge.

The present study explored textual comprehension only, which mainly involved readers recalling information rather than using it to integrate with what they already know or to form judgements based on multiple text parts. The study indicated that, for this basic understanding of a text, reading on screen may be just as good as reading on paper. However, future research should investigate the effect of text media on deeper comprehension requiring critical analysis and inferential cognitive processes to be generalisable a range of reading purposes.

Chapter 5: Experiment 2 – The Effect of Study Time Pressure on Navigation and Comprehension of Hypertext

This chapter will describe the second in a series of empirical experiments which assess how students learn from and navigate hypertext, as well as the differences between print and digital text learning. The primary focus of Study 2 will be to explore the effect of time pressure on learning across study media. Furthermore, it will assess the effect of print versus digital text learning on different levels of comprehension. The methodology used in this experiment is similar to Study 1 (see Chapter 4), so the method section of this chapter will only detail that which has not been described in an earlier chapter.

5.1 Background

5.1.1 Time Pressure

Time pressure has been conceptualised as the subjective feeling of a shortage of time, which may lead to adverse psychological consequences. For example, Svenson and Edland (1993) stated that "time constraints may lead to the experience of time pressure and more intense time pressure may increase the level of arousal and psychological stress" (p. 367). This is relevant for academic settings, where students are often required to study for exams and read learning materials before deadlines. Previous research has found that many students frequently study difficult texts under time constraints, because they often delay study activities until absolutely necessary such as in the days before an exam (Onwuegbuzie 2004; Solomon & Murakami, 1986). Studies assessing the prevalence for such procrastination among college students in a range of academic courses across several countries estimate the rate to be around 80% (Abbasi & Alghamdi, 2015; Afzal & Jami, 2018; Mohammadi

Bytamar et al., 2017; Steel & Ferrari, 2013). Therefore, it is important to understand the impact of time pressure on learning processes and outcomes, particularly when the study task requires reading complex online texts such as hypertext. Few investigations into the role of time pressure in learning across study media have been conducted.

There is some debate about whether either low, moderate, or high time pressure has a positive or negative impact on comprehension. For instance, the absence of time constraints allows for self-regulated study in which readers make their own decisions (e.g., choosing to read certain information, navigating to a particular page, when to terminate study time), which may allow for the opportunity to achieve mastery of the presented information resulting in increased comprehension (Nelson & Naren, 1994). Alternatively, high time pressure has been associated with compromising students' reading goals, with it affecting self-control over study efforts, strategic allocation of cognitive resources, and efficiency of learning behaviour (Kellogg et al., 1999; Thiede & Kürschner, 2007; Tullis & Benjamin, 2011). Others have demonstrated how moderate time pressure may lead to improved performance on a range of learning tasks, such as reading comprehension (Dunlosky & Thiede, 2004; Henderson et al., 2007; Kellogg et al., 1999; Walczyk et al., 1999), online search (Wu & Xie, 2018), Stroop (Chajut & Algom, 2003), computer maze (Slobounov et al., 2000), and arithmetic and probe tasks (Qi et al., 2018). The present study will explore the impact of low, moderate, and high time pressure on students' learning and navigation of digital and print texts.

The results from studies showing a positive relation between moderate time pressure and reading comprehension may be explained by time pressure helping learners prioritise task-relevant information through the mechanism of active

cognitive control of attention and avoidance of distractions for irrelevant stimuli (Lavie et al., 2004). When an individual is aware of how long they have to read a text they may be able to plan their time more effectively, enabling them to prioritise the learning of certain information to get them closer to their reading goal. The 'region of proximal learning' model of study time allocation provides a guide as to which information a learner will choose to allocate more cognitive resources and effort to. Under no time pressure, it has been suggested that readers of expository texts choose to study the most difficult information, whereas under greater time pressure they tend to give higher priority to easier items (Kornell et al., 2016; Metcalfe & Kornell, 2005).

Therefore, the present study predicts that readers under greater time pressure will have weaker comprehension scores for more difficult integration items. In addition, it is predicted that hypertext readers under greater time pressure will be particularly disadvantaged when answering integration items because of the additional complexity of reading and navigating this type of text over print texts.

5.1.2 Relation to Reading Comprehension and Learning

The present study will assess different levels of reading comprehension. Textual comprehension assessments usually require specific details of a text to be recalled, focusing on readers' memory of information like dates, names, or facts (Hosp & Suchey, 2014). While types of assessment items are typically multiple-choice or closed answer, and do not require the reader to go beyond what the text explicitly states (Tarchi, 2017), inferential comprehension assessment items may require inferences to be made based on parts of the text, across parts, or require the integration of prior knowledge (Cain et al., 2004; Clinton & van den Broek, 2012).

Inferential items are typically short-answer or essay-based and are considered more difficult than textual measures (Basaraba et al., 2013).

Reading under greater amounts of time pressure may inhibit the more effortful cognitive processes necessary to gain a deeper comprehension of a text. One study provided participants with false information about a college student and asked them to read a passage under varying amounts of time pressure (Gilbert et al, 1993). They were then instructed to make judgements about the student (e.g., whether they were likable or not). Those who read the passage under high time pressure were more likely to believe the false information and use it in evaluating the individual. The researchers concluded that when under high time pressure, individuals are less likely to think critically about textual information. Similarly, Walczyk's (1995) experiment involved individuals reading expository passages under no time pressure or high time pressure (50% less reading time). Participants' reading comprehension scores were significantly higher for those under no time pressure. These studies show that deeper comprehension processes such as evaluating may be negatively impacted by the presence of high time pressure.

While the influence of time pressure on other learning tasks has also been assessed, most of this research has tested simple learning tasks such as memorising pairs of words (Metcalfe, 2002) or deciding whether to gamble (DeDonno & Demaree, 2008). One study that sought to examine more complex processes investigated the effect of prior experience on two different reasoning tests with and without time pressure (Chuderski, 2016). A sample of young adults completed the computerised Raven's Matrices Test, in which participants discovered the rules that governed a geometric pattern with one fragment missing, in order to choose a correct option of responses that fitted that pattern. Finding that participants under no time

pressure performed best, the researcher interpreted the results to mean that time pressure prevents relational learning, but that such learning can occur when no time pressure exists.

However, some time pressure may be beneficial for learning. One study explored the relation between time limitations and reading comprehension for college students (Walczyk, et al., 1999). Participants read passages presented on screen under low, moderate, and high time pressure. Those reading under moderate time pressure had the best reading comprehension scores, leading the researchers to suggest that moderate time pressure may improve readers' mindfulness (exertion of more effort and motivation) during the act of reading. When students are aware that they have a certain amount of time in which to learn textual material, it may help focus their attention and inhibit the processing of distracting or irrelevant information.

More recently, Wu and Xie (2018) investigated the effect of note-taking strategies and time pressure on university students' task-irrelevant browsing behaviours and online search performance. The study found that notetaking and time pressure (high versus low pressure) reduced irrelevant browsing and enhanced online search performance. The researchers concluded that the presence of time pressure meant that participants' cognitive control mechanisms selectively oriented their attention towards more task-relevant information, and away from distraction sources when browsing online (such as social media websites).

5.1.3 Relation to Working Memory

Working memory is the set of mental resources that individuals use to encode, activate, store, and manipulate information while they perform cognitive

tasks (Baddeley, 2003). Previous research has suggested that the awareness of time constraints may distract learners from their reading task, resulting in more working memory resources being used, and leaving less to spare for processing the current task (Dunlosky & Thiede, 2004; Kellogg et al., 1999). Therefore, reading under greater amounts of time pressure may be particularly detrimental for individuals with low working memory capacity, as their working memory stores may be depleted quicker than those with high capacities, leading to weaker comprehension. In addition, DeStefano and LeFevre's (2007) process model of hypertext reading suggests the additional processing demands of hypertext reading (e.g., deciding whether to click a hyperlink and recalling its location in relation to others) may also overburden readers' working memory stores, leading to weaker comprehension. Therefore, the present study predicts that low working memory capacity readers of hypertext will be especially disadvantaged when learning under high time pressure. Furthermore, it is predicted that these readers will be especially disadvantaged on integration comprehension.

5.1.4 Relation to Metacognitive Experience

The set of metacognitive processes involved in reading is called 'metacognitive learning regulation', which includes self-monitoring behaviour such as applying learned reading strategies, deciding to revisit more difficult sections, or investing more study time to particular items (Brown, 1987). Self-control over study efforts is an important factor in achieving effective regulation of learning, and this is particularly evident when individuals are aware of a fixed study time as they can strategically allocate their cognitive resources according to their motivation, perceived skills, and perceived difficulty of the task (Ackerman & Lauterman 2012; Pintrich, 2003; Schunk, 2005; Tulis & Benjamin, 2011).

One study investigated the relation between metacognitive skilfulness, text difficulty, and study time constraints when studying (Veenman & Beishuizen, 2004). A sample of 46 social science students studied either a difficult (forensic psychology) or easy (agriculture) expository text under time pressure, and were assessed on a multiple-choice comprehension test. The text was presented on paper and resembled textbook chapters. A think-aloud protocol was used to score metacognitive skilfulness including orientation, planning, evaluation, and elaboration. The researchers found that these metacognitive skills contributed to comprehension of both texts. In addition, greater study time pressure impaired text comprehension for those reading the difficult text.

Ackerman and Goldsmith (2011) found that while there was no difference in students' comprehension test scores between study medium (print versus digital text) when the study time was fixed (moderate time pressure), under no time pressure, screen learning produced lower test scores compared to those learning on paper. The researchers discounted technology-related factors as being the main source of learning differences between study medium, and instead suggested the results reflected an inefficiency of metacognitive processes such as time allocation, monitoring, and control, when learning from digital texts.

5.1.5 Relation to Hypertext Navigation

The present study will explore hypertext readers' navigation by examining log files. Within the no time pressure condition, readers will decide when to stop reading the text. Deciding when to stop may seem straightforward: stop when the information has been learned. However, factors such as item difficulty and time pressure may mean learners stop studying even when they do not know the

information, such as when aiming for partial knowledge rather than complete mastery (Kornell & Bjork, 2007). According to the 'Discrepancy Reduction Model', learners begin their study activity by settings themselves a target level of subjective satisfactory knowledge acquisition (Nelson & Narens, 1990; Dunlosky & Thiede, 1998). When the target level an individual has set themselves has been reached, the learner may choose to terminate the study of that item and move on to another.

The Region of Proximal Learning model suggests that some learners take a pragmatic approach to reading texts; they read the information to the point where they have enough knowledge to understand the text, and then may decide to either continue reading to gain a deeper understanding of the text, or stop (Metcalfe, 2002; Metcalfe & Kornell, 2003). Previous research has found that, when under high time pressure, readers sometimes prioritise learning more basic information rather than gaining a deeper understanding of a text to get closer to their reading goal more quickly (Chuderski, 2013; Kornell et al., 2016; Metcalfe, 2002; Metcalfe & Kornell, 2005; Son & Metcalfe, 2000). As a result, it is predicted that hypertext readers under greater time pressure will make fewer revisits to previously read pages, as they will attempt to locate and read all of the information once rather than spend time rereading to rehearse and integrate information across pages. Log files will be examined to explore how students navigate through hypertext under different amounts of time pressure, and how this relates to their comprehension of the text.

5.2 Aims and Hypotheses

An experiment was conducted with the aim of investigating the effect of study time pressure on how students learn from and navigate through hypertext. It also explored the differences between print and digital text learning. The

relationship between working memory, metacognitive experience, navigation behaviour, and comprehension was assessed for readers of print text, scrolling text, structured hypertext, and networked hypertext. It sought to address the following hypotheses:

H_1: Print text readers will score higher on a reading comprehension test than scrolling text, structured hypertext, and networked hypertext readers, with integration comprehension being weakest in hypertext.

H_2: Participants reading under high time pressure score lower on a reading comprehension test than those in both the low and moderate time pressure conditions, with high time pressure negatively impacting hypertext readers the most.

H_3: The verbal and visuospatial working memory of networked hypertext readers under high time pressure conditions will be strongly positively correlated with comprehension test scores.

H_4: Participants under moderate and high time pressure will report greater navigational difficulties (e.g., disorientation) than those under no time pressure, with hypertext readers under high time pressure reporting the most navigational difficulties of all groups.

5.3 Method

Measures retained in this study from the previous experiment (Chapter 4) include: informational text about the Battle of Trafalgar, verbal and visuospatial working memory test, measure of switching ability, PIEpre and PIEpost

questionnaires, and metacognitive items (judgements of learning and confidence ratings). Only new or enhanced measures will be described in this section.

5.3.1 Design

This study made use of a between-subjects experimental design in which 90 participants were assigned to one of the following four reading conditions: print text (N = 24), scrolling text (N = 20); structured hypertext (N = 22), or networked hypertext (N = 24). Groups were subdivided into three different reading time allocations: 20 minutes (moderate time pressure), 20 minutes with interruption (5-minutes-remaining warning prompt; high time pressure), and free regulation (no time limit; no time pressure). This resulted in participants being placed into one of 12 conditions (see Figure 5.1 for overview of reading conditions). Participants were randomly assigned, and blinded to, their conditions.

Participants read the same informational text as used in experiment one (see Chapter 4), and the hypertexts were structured as described previously. They completed the reading task and questionnaires during one 60-minute testing session. Table 5.2 gives a brief description of the time pressure allocations.

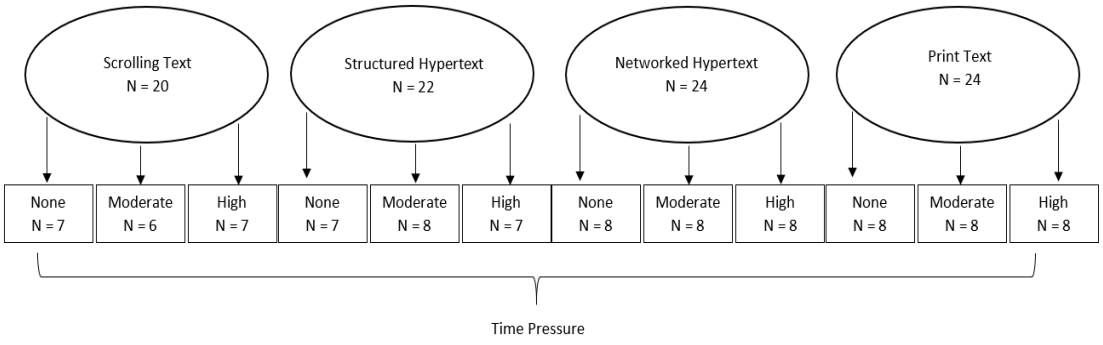


Figure 5.1. Overview of conditions.

Table 5.2

Descriptions of each reading time pressure group.

Reading Condition	Description
No Time Pressure	When doing the reading task, participants are informed that there is no limit on how long they have to read the text. They are instructed to inform the experimenter when they would like to stop the reading task and move on to the remaining questionnaires.
Moderate Time Pressure	Participants are informed that they have 20 minutes to complete the reading task. The experimenter informs the participants once their 20 minutes reading time is complete, and they move on to the remaining questionnaires.
High Time Pressure	Participants are not informed how long they have to read the text. Instead, they are told that the experimenter will inform them when they have 5 minutes reading time remaining. After 15 minutes reading time, the experimenter delivers the 5-minute warning prompt. After 20 minutes' time has passed, the experimenter informs the participant that their reading time is complete. They complete the remaining questionnaires.

5.3.2 Participants

The study consisted of a sample of 90 healthy participants, recruited from the university campus via an online study recruitment program. There were 16 males (17.8%) and 74 females (82.2%), ranging between 18 and 42 years of age (M = 20.47, SD = 3.96). Individuals who responded to the experimenters were allocated a timeslot to participate, and those who successfully completed the study received 60 participation credits. Participants were not subject to any exclusion criteria.

5.3.3 Comprehension Test

As the previous experiment used a comprehension test consisting of textual items only, this experiment improved the test by including both textual and inferential comprehension items. Of the 30 total items, 21 were multiple-choice and assessed textual comprehension, while the remaining 9 were short-answer and assessed inferential comprehension (called 'integration items' in subsequent sections).

5.3.4 Reading Strategies

As it was identified that the reading strategies questionnaire used in the previous experiment did not capture the full range of strategies readers may have used during the reading task, an enhanced questionnaire was devised which included a total of 35 statements relating to their use of time (five items were responded to by high time pressure participants only).

5.4 Procedure

The procedure used in the experiment was the same as in experiment 1 (see Chapter 4), except for the following changes:

In addition to being randomly assigned to one of four reading conditions (print text, scrolling text, structured hypertext, networked hypertext), participants were also randomly assigned to one of three reading times: no time pressure (no reading time limit), moderate time pressure (20 minutes reading time), or high time pressure (five-minute warning prompt after 15 minutes reading time). Those in the no time pressure condition were told that there would no limit on how long they have to read the text, and that they must inform the experimenter when they would like to

stop the reading task and move on to the remaining questionnaires. Those in the moderate time pressure condition were told that that they would have 20 minutes to complete the reading task, and that the experimenter will inform them once their 20 minutes reading time is complete. Participants in the high time pressure condition were not told how long they would have to read the text, but that they would be told by the experimenter when they had five minutes reading time remaining. After 15 minutes reading time, the experimenter delivered the five-minute warning prompt. After 20 minutes' total reading time had passed, the experimenter informed the participant that their reading time was complete.

5.5 Results

This section will report the results of the present experiment. Reading comprehension and time pressure results will be reported first, followed by working memory, confidence ratings, PIE, reading strategies, and navigation measures.

5.5.1 Reading Comprehension

All 30 reading comprehension items were scored as either correct (1) or incorrect (0) for a maximum overall score of 30, a maximum textual score of 21, and a maximum integration score of 9. Overall, test scores ranged from 4 to 28 with a mean score of 16.91. There was a mean textual score of 14.59, and a mean integration score of 2.32. Participants performed best when they read scrolling text under no time pressure. These data are shown in Table 5.3. Reliability analyses of the reading comprehension test questions showed a sufficient Cronbach's alpha for both the textual (α = .69) and integration items (α = .77).

Overall Scores. The hypothesis **H_1** predicted that those in the print text condition would have significantly higher comprehension scores than those in both of the hypertext conditions. A two-way between-subjects ANOVA was conducted to assess the effect of reading condition and time pressure on overall comprehension test scores. In support of **H_1**, there was a significant main effect of reading condition on overall test scores, $F(3, 78) = 4.61$, $p = .005$, partial $\eta^2 = .151$. Participants in the print text condition performed significantly better than those in both the structured ($p = .016$) and networked ($p = .002$) hypertext conditions. Participants in the scrolling text condition performed significantly better than those in networked hypertext condition ($p = .014$). However, there was no significant difference between scores for those in the print text and scrolling text conditions ($p = .555$) or structured and networked hypertext conditions ($p = .460$).

The hypothesis **H_2** predicted that those in the high time pressure condition would have significantly weaker comprehension scores than those in the moderate and no time pressure conditions. Challenging **H_2**, there was no significant main effect of time pressure on overall comprehension test scores, $F(2, 78) = 2.09$, $p = .131$, partial $\eta^2 = .051$. The main effects on overall comprehension test scores were modified by a significant interaction between reading condition and time pressure, $F(6, 78) = 2.70$, $p = .019$, partial $\eta^2 = .172$; for scrolling text, those under no time pressure ($M = 23.14$, $SD = 4.95$) performed better than those under moderate time pressure ($M = 14.33$, $SD = 5.61$), $p = .005$.

Textual Scores. A two-way between subjects ANOVA conducted to assess the effect of reading condition and time pressure on correct responses for the 21 textual items in the comprehension test, found a significant main effect of reading condition on textual item scores, $F(3, 78) = 4.13$, $p = .009$, partial $\eta^2 = .137$, with

those in the print text condition performing significantly better than those in both the structured (p = .018) and networked (p = .001) hypertext conditions. There was no significant main effect of time pressure on textual test scores, $F(2, 78) = .214$, p = .808, partial η^2 = .005.

A significant interaction between reading condition and time pressure, $F(6, 78) = 2.67$, p = .021, partial η^2 = .170, found that scrolling text readers performed better under no time pressure than under moderate time pressure. When there was no time pressure, scrolling text readers performed better than networked hypertext readers.

Integration Scores. A two-way between-subjects ANOVA which assessed the effect of reading condition and time pressure on correct responses for the 9 integration comprehension items found a significant main effect of reading condition on integration scores, $F(3, 78) = 3.25$, p = .026, partial η^2 = .111. Print text readers performed better than those in the networked hypertext condition (p = .050), whereas scrolling text readers performed significantly better than those in both the structured (p = .023) and networked (p = .009) hypertext conditions.

There was also a significant main effect of time pressure on integration scores, $F(2, 78) = 6.66$, p = .002, partial η^2 = .146. Participants under no time pressure performed significantly better than those in the high time pressure condition ($p < .001$). There was no interaction effect of text condition and time pressure (p = 155).

Table 5.3

Overall, textual, and integration comprehension scores across all groups.

Comp.	Time	Text Condition							
		Print		Scrolling		S. H'text		N. H'text	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	18.83	7.25	23.14	4.95	17.57	4.28	13.25	3.06
	Mod.	20.63	2.33	14.33	5.61	15.75	2.38	16.25	5.60
	High	17.63	4.90	17.00	4.12	13.86	2.41	14.75	4.27
Textual	Low	15.25	5.31	17.43	3.05	15.29	2.43	11.50	2.33
	Mod.	17.38	1.41	12.33	3.08	13.88	1.46	13.88	3.87
	High	16.00	3.55	15.00	3.06	12.71	2.93	14.13	3.09
Integration	Low	3.37	2.45	5.71	2.36	2.29	2.75	1.75	1.75
	Mod.	3.25	1.58	2.00	2.97	1.88	1.55	2.38	2.67
	High	1.63	1.60	2.00	2.08	1.14	1.07	.63	.92
Range (min. – max. score)		22 (4-26)		18 (10-28)		16 (10-26)		17 (8-25)	

5.5.2 Working Memory

Analyses were conducted to test the relationships between working memory and comprehension across study media and time pressure groups. Since there was a significant positive correlation between verbal span and raw scores, $r(90) = .940$, $p < .001$, and visuospatial span and raw scores, $r(90) = .932$, $p < .001$, only verbal and visuospatial raw scores will be reported.

Switching Ability

Performance on the trail-making task (scored as previously described in Chapter 4) is shown in Table 5.4. There was no significant difference in total

completion time between the 12 groups for either the number sequencing, $F(3, 89) = .644$, $p = .589$, partial $\eta^2 = .022$, or set-shifting trials, $F(3, 89) = 1.14$, $p = .339$, partial $\eta^2 = .038$. Switch-cost was also calculated (the higher the value, the greater the cost of switching between processing tasks), finding no significant differences in switch-cost scores between text condition, $F(3, 78) = 1.20$, $p = .315$, partial $\eta^2 = .044$, or time pressure groups, $F(3, 78) = 1.13$, $p = .327$, partial $\eta^2 = .028$.

Table 5.4

Performance on each trial of the trail-making task and switch-cost scores across all groups.

Trial	Time	Print		Scrolling		S. H'text		N. H'text	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sequencing	Low	27.86	6.00	22.63	9.81	22.51	7.26	20.31	7.85
	Mod.	21.47	5.22	18.29	4.24	25.47	7.29	19.42	6.16
	High	21.23	6.38	23.00	6.24	21.17	6.90	23.00	13.22
Set-Shifting	Low	57.65	12.32	43.80	10.31	35.75	12.74	44.55	13.49
	Mod.	49.25	15.56	40.29	14.54	59.72	27.62	42.71	13.62
	High	54.45	20.56	52.98	16.09	39.46	8.03	22.99	13.22
Switch-Cost	Low	29.78	13.18	21.17	6.42	13.24	6.57	24.24	8.80
	Mod.	27.78	16.33	22.01	13.49	34.25	26.39	23.28	10.22
	High	33.22	15.94	29.98	12.44	18.28	6.49	29.12	26.03

Pearson's correlations tested the relationships between both trials, switch-cost, and comprehension across each condition, finding no significant correlations (Table 5.5).

Table 5.5

Correlations between both trials of the trail-making task, switch-cost scores, and comprehension.

Trial	Comprehension					
	Overall		Textual		Integration	
	r	*p*	*r*	*p*	*r*	*p*
Sequencing	-.013	.904	-.025	.813	.010	.927
Set-Shifting	.037	.731	.051	.634	.004	.972
Switch-Cost	.048	.652	.070	.510	.000	.997

Verbal Working Memory

Performance on the verbal working memory test (scored as previously described) was best for forwards order (M = 7.69, SD = 1.50), and weakest for reverse order (M = 5.06, SD = 1.27). There were no significant differences in verbal working memory scores between text condition, $F(3, 90) = 1.33$, $p = .270$, partial $\eta^2 = .049$, or time pressure groups, $F(2, 50) = .30$, $p = .745$, partial $\eta^2 = .008$, meaning each group included participants of similar verbal working memory ability (Table 5.6).

Table 5.6

Descriptive statistics for each trial of verbal working memory test across all groups.

Trial	Time	Print		Scrolling		S. H'text		N. H'text	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	19.88	3.94	17.29	3.35	19.00	3.06	18.00	3.34
	Mod.	18.88	3.09	20.88	4.31	17.00	3.63	18.63	4.53
	High	19.75	2.96	17.43	.79	16.43	3.21	19.00	3.46
Forwards	Low	8.63	2.00	7.43	1.72	7.71	1.89	7.88	1.25
	Mod.	7.63	1.92	7.83	1.33	7.13	1.36	7.75	2.05
	High	8.00	1.31	7.14	.90	7.00	.82	8.00	1.07
Reverse	Low	5.75	1.28	3.86	1.35	3.86	1.35	4.63	1.30
	Mod.	5.75	1.04	5.67	1.63	4.63	1.06	5.00	1.07
	High	5.50	1.07	4.71	1.11	4.29	1.11	5.38	1.30
Sequencing	Low	5.50	1.20	6.00	1.83	5.86	1.07	5.50	1.85
	Mod.	5.50	1.07	7.33	2.66	5.25	1.75	5.88	2.36
	High	6.25	1.75	5.29	1.11	5.14	1.68	5.50	1.93

Pearson's correlations found a significant positive relationship between total verbal working memory scores and textual comprehension across all conditions, $r(90) = .211$, $p = .046$, meaning the greater participants' verbal working memory scores, the higher they scored on the textual comprehension. There was no relationship between verbal scores and integration comprehension. Additional correlations assessed the relationship between verbal working memory and comprehension for each of the 12 groups separately, finding the verbal working memory of those in the structured hypertext group was positively correlated with

overall comprehension (p = .043), and the verbal working memory of those in the networked hypertext group was positively correlated with higher textual comprehension (p = .022; Table 5.7). There were no significant correlations between verbal working memory and comprehension scores in either of the time pressure groups.

Table 5.7

Correlations between verbal working memory and comprehension for each condition.

Condition/Comprehension	Overall		Textual		Integration	
	r	*p*	*r*	*p*	*r*	*p*
Print Text	.347	.096	.344	.099	.254	.231
Scrolling Text	-.062	.794	-.234	.321	.157	.510
Structured H'text	**.435**	**.043***	.323	.142	.351	.109
Networked H'text	.396	.056	**.466**	**.022***	.087	.686

***** significant to $p < .05$.

Visuospatial Working Memory

Performance on the visuospatial working memory test (scores as previously described) was best for forwards order (M = 7.94, SD = 1.60), and weakest for reverse order (M = 7.31, SD = 1.87). There were no significant differences in verbal working memory scores between text condition, $F(3, 90) = 2.28$, p = .092, partial η^2 = .079, or time pressure groups, $F(2, 50) = 1.95$, p = .149, partial η^2 = .048, meaning each group included participants of similar visuospatial working memory ability (Table 5.8).

Table 5.8

Descriptive statistics for each trial of visuospatial working memory test across all groups.

Trial	Time	Print		Scrolling		S. H'text		N. H'text	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	16.63	2.45	15.00	3.37	18.14	2.34	14.25	2.55
	Mod.	15.75	2.43	14.83	4.49	14.88	3.09	15.38	4.21
	High	16.13	2.23	14.00	2.25	15.57	2.30	13.38	2.33
Forward	Low	8.63	1.06	8.14	1.95	9.14	1.46	7.75	1.39
	Mod.	8.13	1.25	8.33	1.86	7.38	1.60	8.25	2.55
	High	8.00	1.77	7.14	.90	7.71	1.38	6.88	1.13
Reverse	Low	8.00	1.77	6.86	2.27	9.00	1.15	6.50	1.60
	Mod.	7.63	1.51	7.50	1.77	7.50	1.98	7.25	1.98
	High	8.13	1.16	6.86	1.46	6.86	1.46	6.50	2.20

Pearson's correlations found a significant positive between visuospatial working memory and both textual [$r(90) = .258$, $p = .014$] and integration [$r(90) = .251$, $p = .017$] comprehension. Additional correlations which assessed the relationship between visuospatial working memory and comprehension for each of the 12 groups separately, found visuospatial working memory was positively correlated with overall ($p = .026$) and textual ($p = .018$) comprehension for networked hypertext readers only (Table 5.9). Visuospatial working memory was positively related to overall and textual comprehension in readers under moderate time pressure, was positively related to overall, textual, and integration comprehension in readers under high time pressure.

Table 5.9

Correlations between visuospatial working and comprehension for each condition.

Condition/Comprehension		Overall		Textual		Integration	
		r	*p*	*r*	*p*	*r*	*p*
Text	Print Text	.236	.286	.154	.474	.321	.126
	Scrolling Text	.175	.460	.059	.803	.281	.230
	Structured H'text	.292	.187	.182	.418	.281	.205
	Networked H'text	**.455**	**.026***	**.479**	**.018***	.193	.366
Time	Low	-.044	.816	-.070	.712	.005	.978
	Moderate	**.441**	**.015***	**.440**	**< .001***	.308	.098
	High	**.571**	**.001***	**.517**	**.003***	**.422**	**.020***

***** significant to $p < .05$.

To summarise the results for working memory, there was no relationship between switching ability and comprehension, but there was a positive relationship between verbal and visuospatial working memory and overall and textual comprehension across each text condition. There was also a positive relationship between visuospatial working memory and integration comprehension, but not for verbal working memory and integration. In support of **H3**, the verbal and visuospatial working memory of networked hypertext readers under high time pressure conditions was strongly positively correlated with comprehension test scores

5.5.3 Metacognition

JoL Ratings. Taking the average of all JoL ratings for each condition (calculated as described in Chapter 4), those in the networked hypertext reading

condition generally gave lower certainty ratings (M = .49, SD = .16) compared to the scrolling text (M = .60, SD = .19), structured hypertext (M = .51, SD = .18), and print text (M = .56, SD = .16) conditions. A two-way MANOVA found no significant main effect of text condition, $F(90, 153) = 1.32$, $p = .068$, partial $\eta^2 = .436$, or time pressure, $F(60, 100) = 1.12$, $p = .309$, partial $\eta^2 = .401$, on overall JoL ratings.

Confidence Ratings. Each of the 30 JoL ratings were highly correlated with the confidence ratings, meaning that answering the questions in the comprehension test did not affect the level of certainty participants had that they answered correctly. The average confidence ratings for each condition were calculated, and the same pattern as the JoL ratings was found: those in the networked hypertext reading condition generally gave lower certainty ratings (M = .46, SD = .21) compared to the scrolling text (M = .62, SD = .18), structured hypertext (M = .51, SD = .21), and print text (M = .61, SD = .20) conditions.

The average JoL and confidence ratings for each condition were compared with the average actual performance of participants on the comprehension test. Both confidence and JoL ratings are lower than the actual overall question accuracy for the structured hypertext, networked hypertext, and print text conditions, whereas actual performance was slightly lower than the confidence rating for those in the scrolling text condition, suggesting that participants were underconfident in print, structured, and networked hypertext, and overconfident in scrolling text.

5.5.4 Prior Knowledge, Interest, and Effort (PIE)

Before taking part in the reading task, participants first completed the PIEpre questionnaire, in which they were asked to rate on a six-point scale their prior knowledge of the Battle of Trafalgar (M = 1.19, SD = .45), their interest in the topic

(*M* = 2.93, *SD* = 1.47), and how much effort they believed would be required to learn the information (*M* = 4.79, *SD* = .93). They also predicted they would be able to answer less than half of all questions correctly (*M* = 13.49, *SD* = 5.38). The descriptive statistics for both the PIEpre and PIEpost questionnaires are displayed in Table 5.10.

Table 5.10

Descriptive statistics for PIEpre and PIEpost measures across all conditions.

Measure	Pre/Post	Reading Condition							
		Print		Scrolling		S. H'text		N. H'text	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
PK (1-6)	Pre	1.21	.51	1.30	.57	1.05	.21	1.21	.41
	Post	3.92	1.38	3.75	1.33	3.82	1.05	3.25	1.29
I (1-6)	Pre	3.71	1.49	3.20	1.47	2.27	1.42	2.54	1.14
	Post	3.63	1.56	4.20	1.24	3.18	1.79	2.92	1.28
E (1-6)	Pre	4.46	.78	5.00	.86	4.82	1.01	4.92	1.02
	Post	4.58	.88	4.45	1.39	4.50	1.44	4.58	1.35
P (0-30)	Pre	14.71	6.05	13.20	5.95	13.09	5.46	12.88	4.09
	Post	14.79	6.19	14.45	7.05	11.77	4.47	10.04	4.59

Note. **PK** = Prior knowledge; **I** = Interest; **E** = Effort; **P** = Prediction.

A Pearson's correlation revealed that, overall, there was a significant positive relationship between participants' pre-test [$r(90) = .234$, $p = .026$] and post-test [$r(90) = .708$, $p < .001$] predictions and their final comprehension test scores,. Therefore, participants were generally accurate at predicting how many questions they would answer correctly before and after they completed the reading task.

Further tests found that for those in the print text [$r(25) = .538$, $p < .001$], scrolling text [$r(20) = .815$, $p < .001$] and networked hypertext [$r(24) = .766$, $p < .001$] conditions, post-test predictions were significantly positively correlated with their final comprehension test scores. Pre and post-test were also positively correlated with actual comprehension scores across time pressure groups.

A two-way between subjects ANOVA was conducted to test whether there were any differences between time pressure or reading condition for post-test comprehension score predictions. There was a significant main effect of reading condition on post-test comprehension test score predictions, $F(3, 78) = 4.12$, $p = .009$, partial $\eta^2 = .137$, with those in the print text ($p = .002$) and scrolling text ($p = .010$) reading conditions reporting significantly higher predictions than those in the networked hypertext condition. There was no main effect of time pressure on post-test predictions, $F(3, 78) = 2.06$, $p = .134$, partial $\eta^2 = .050$. The results were not modified by any interaction effects ($p = .103$).

For each reading and time pressure condition, there was an underconfidence in post-test predictions, with the lowest average post-test predictions reported by those in the networked reading condition under no time pressure ($M = 8.63$, $SD = 2.39$), and the highest average post-test predictions reported by those in the scrolling text condition under no time pressure ($M = 20.29$, $SD = 5.53$). Figure 5.11 shows the mean comprehension predictions and actual test scores for each text and time pressure condition.

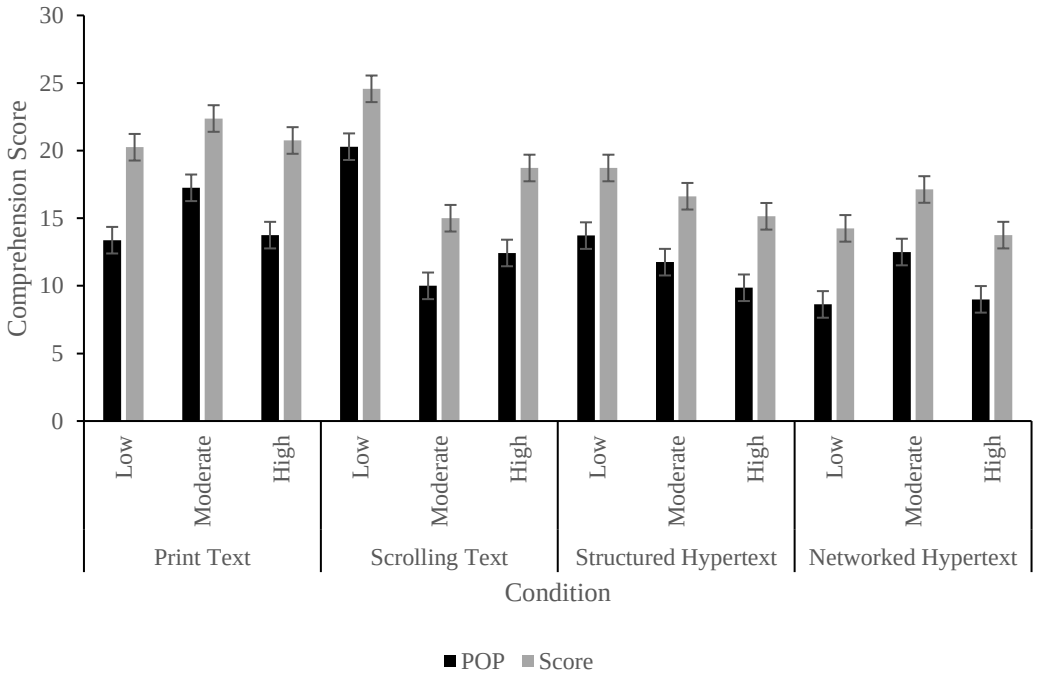


Figure 5.11. Mean comprehension test predictions and scores.

A series of t-tests were conducted for PIEpre and PIEpost questionnaire measures of knowledge, interest, and effort, to assess whether participants' ratings had either increased or decreased from before they completed the reading task and comprehension questions to after they had done so. They found that overall there was a significant increase in participants' knowledge of the topic from pre-test (M = .119, SD = .45), to post-test (M = 3.68, SD = 1.28), $t(89) = -17.92$, $p < .001$, a significant increase in interest from pre-test (M = 2.93, SD = 1.47), to post-test (M = 3.46, SD = 1.64), $t(89) = -3.56$, $p = .001$, and a significant difference between the amount of effort participants predicted would be required to answer the comprehension questions (M = 4.79, SD = .93) and the amount of effort they reported (M = 4.53, SD = 1.18), $t(89) = 2.21$, $p = .030$.

5.5.5 Reading Strategies

A two-way between subjects MANOVA conducted to assess whether there were any differences between groups on responses to the 35 reading strategies items, found no significant main effect of text condition, $F(69, 9) = .552$, $p = .918$, partial $\eta^2 = .809$, or time pressure, $F(23, 1) = 4.80$, $p = .348$, partial $\eta^2 = .991$. There was no interaction effect of text and time pressure condition ($p = .759$). Table 5.12 shows the average overall scores for each of the 35 reading strategy items across all conditions.

Overall, the most preferred strategies were to 'memorise as much as possible' ($M = 7.28$, $SD = 2.40$), and to 'memorise what I thought was important' ($M = 7.28$, $SD = 2.22$). The least preferred strategies were to 'memorise each page/section separately rather than as a whole' ($M = 2.17$, $SD = 1.94$), and to 'test myself to be sure I knew the material' ($M = 3.17$, $SD = 2.59$). Of the questions relating to what participants usually do when they read informational texts, the most preferred responses were 'I find it easier to learn new information when I have no reading time limit' ($M = 7.72$, $SD = 2.33$), and 'I find it easier to learn new information when I can distinguish between the beginning, middle, and end of a text' ($M = 8.93$, $SD = 1.51$). The least preferred responses were 'I take the time to become familiar with a website's layout before I read the information' ($M = 3.34$, $SD = 2.70$) and, 'Usually I only need to read a new piece of information once to remember it' ($M = 6.34$, $SD = 2.78$).

Table 5.12

Overall scores for each of the 35 reading strategies questionnaire item, in order of average scores.

Question Number	Description	*M*	*SD*
27	‘When no reading time limit”	8.93	1.51
18	‘Beginning, middle, and end’	7.72	2.33
28	‘Easily distracted’	7.59	1.84
4	‘Memorise’	7.28	2.40
6	‘Thought was important’	7.28	2.22
15	‘Remembered facts’	7.21	2.61
8	‘Stopped to read through’	6.86	2.55
1	‘Connections’	6.83	2.30
3	‘Overview’	6.83	2.33
32	‘Revisited as many’	6.72	2.96
20	‘Aim of task’	6.66	2.33
31	‘As quickly as possible’	6.55	3.10
16	‘Used time differently”	6.48	2.57
21	‘Lost/confused’	6.38	2.56
12	‘Difficult pages/sections’	6.34	2.78
13	‘Easy to locate’	6.31	2.94
23	‘Connections similar’	6.31	2.35
30	‘Revisited specific’	6.31	3.31
19	‘Attentive to time’	6.17	2.64
5	‘Most important’	6.07	2.07
33	‘Aim of the task in mind’	5.93	3.26
14	‘Longer pages/sections’	5.72	2.94
24	‘Beginning, middle, and end’	5.17	2.54
2	‘Summarised’	4.97	2.13

Question Number	Description	*M*	*SD*
34	'Skim-read all'	4.90	3.49
7	'Practiced'	4.52	2.59
35	'Changed navigation'	4.17	2.88
17	'Navigation plan'	3.90	2.73
10	'Easy to recall'	3.76	2.49
29	'Used pictures'	3.62	3.26
26	'Strategic in use of time'	3.41	2.26
22	'Layout'	3.34	2.70
9	'Tested myself'	3.17	2.59
11	'Read information once'	2.69	2.55
25	'Memorised separately'	2.17	1.94

5.5.6 Navigation Behaviour

Analyses were conducted to test whether there was an effect of time pressure or hypertext condition on navigation. The hypothesis **H_4** predicted that strategic and knowledge-seeking navigational behaviours would be related to greater comprehension than non-strategic and feature-seeking behaviours.

Average Time Spent Per Page

A two-way between-subjects ANOVA was conducted to assess whether there was an effect of reading condition or time pressure on average time spent per page (scored as previously described; Table 5.13). There was a significant main effect of reading condition, $F(1, 40) = 5.06$, $p = .030$, partial $\eta^2 = .955$, with readers in the structured hypertext condition spending a significantly greater average amount of time per page than those in the networked hypertext condition. There was no

significant effect of time pressure on average time spent per page, $F(2, 40) = 2.16$, $p = .129$, partial $\eta^2 = .097$.

Table 5.13

Average time (seconds) per page across each condition.

Condition	Time	Average Time Spent (*seconds*)	
		M	*SD*
Overall	Low	117.33	29.48
	Mod.	108.38	26.77
	High	127.80	28.86
Structured H'text	Low	125.14	26.42
	Mod.	113.00	16.89
	High	144.14	33.27
Networked H'text	Low	110.50	14.72
	Mod.	103.75	34.66
	High	113.50	14.71

'Clicking' Behaviour

A two-way between-subjects ANOVA conducted to assess whether there was an effect of reading condition or time pressure on number of clicks made showed no significant main effect of reading condition, $F(1, 40) = .415$, $p = .523$, partial $\eta^2 = .010$, or time pressure condition, $F(1, 40) = .836$, $p = .441$, partial $\eta^2 = .040$ (Table 5.14). Readers in the structured hypertext condition made a similar number of clicks to those in the networked hypertext condition.

Table 5.14

Average number of clicks across each condition.

Condition	Time	Average Number of Clicks	
		M	*SD*
Overall	Low	33.20	15.91
	Mod.	39.31	15.61
	High	32.80	13.42
Structured H'text	Low	37.29	17.73
	Mod.	38.75	16.69
	High	34.00	14.02
Networked H'text	Low	29.63	14.33
	Mod.	39.88	15.59
	High	31.75	13.74

Page Visits

The overall number of page visits was measured by summing the number of times each participant in the structured and networked hypertext conditions visited each one of the 13 pages of the text during the reading task. Participants visited pages 2.0 (*M* = 5.89, *SD* = 3.77) and 1.0 (*M* = 4.93, *SD* = 3.23) the most, and visited pages 2.2 (*M* = .59, *SD* = 1.08) and 5.1 (*M* = .70, *SD* = .82) the least. These data are shown in Table 5.15.

Table 5.15

Overall average number of visits per page.

Page Number	Average Number of Visits	
	M	*SD*
1.0	4.80	2.47
1.1	4.33	2.23
1.2	1.46	1.26
2.0	4.76	2.79
2.1	2.48	2.07
2.2	1.17	1.37
3.0	2.98	1.90
3.1	1.83	1.40
4.0	3.50	2.51
4.1	.70	.66
5.0	3.37	2.89
5.1	1.07	1.16
6.0	1.54	1.39

Total Reading Times

Participants in both the moderate and high time pressure conditions had a total of 20-minutes' reading time, whereas those in the no time pressure condition had an indeterminate time in which to read the text; they decided themselves when to cease reading and move on to the remaining questionnaires. A one-way ANOVA conducted to assess whether there was an effect of text condition on how long

participants read for under no time pressure, found no significant main effect of text condition, $F(3, 22) = 2.72$, $p = .069$, partial $\eta^2 = .270$ (Table 5.16). ~~P~~participants spent roughly the same time reading the text when under no time pressure, regardless of which format they read. On average, participants spent the longest time reading from print text ($M = 23.09$, $SD = 2.23$), and the shortest time reading from networked hypertext ($M = 17.48$, $SD = 6.12$).

Table 5.16

Average reading times for readers under no time pressure (minutes).

Condition	*M*	*SD*
Print Text	23.09	2.23
Scrolling Text	22.62	5.78
Structured H'text	23.03	1.76
Networked H'text	17.48	6.12
Total	21.49	5.20

Study Efficiency

The study efficiency measure was calculated by dividing readers' total comprehension test score by their overall study time to create a 'points per minute' score (Table 5.17). A two-way ANOVA was conducted to assess whether there was an effect of text or time pressure condition on study efficiency scores, finding a significant main effect of text condition on study efficiency scores, $F(3, 78) = 2.86$, $p = .042$, partial $\eta^2 = .099$. Participants in the print text condition ($M = 1.00$, $SD = .29$) had a significantly higher study efficiency score than those in the structured ($M = .80$, $SD = .17$, $p = .014$), and networked ($M = .83$, $SD = .37$, $p = .032$) hypertext

conditions. There was no significant main effect of time pressure condition on study efficiency scores, $F(2, 78) = 1.94$, $p = .366$, partial $\eta^2 = .366$. The most efficient individual condition was scrolling text under no time pressure ($M = 1.17$, $SD = .14$). There was no interaction effect between text condition and time pressure ($p = .085$).

Table 5.17

Study efficiency (points per minute) across each text and time pressure condition.

Condition	Time Pressure	*M*	*SD*
Print Text	Low	.89	.34
	Moderate	1.12	.18
	High	1.01	.31
	Total	1.00	.29
Scrolling Text	Low	1.17	.14
	Moderate	.75	.27
	High	.94	.22
	Total	.96	.29
Structured H'text	Low	.80	.24
	Moderate	.83	.14
	High	.76	.15
	Total	.80	.17
Networked H'text	Low	.94	.49
	Moderate	.86	.31
	High	.69	.25
	Total	.83	.37

Note. **SH** = Structured Hypertext; **NH** = Networked Hypertext

Navigation Styles

Readers' navigation behaviour was investigated to see whether they could be grouped into different types of navigational styles. On average, participants spent 118 seconds per page, made 35 clicks, and scored 17 out of 30 on the reading comprehension test. Table 5.18 shows an overview of the strongest and weakest performers in each group including an interpretation of whether their navigation activities were beneficial for comprehension. Table 5.19 shows an overview of the navigation activity of participants in both hypertexts conditions under high time pressure following the five-minute warning prompt.

Table 5.18

Overview of strongest and weakest hypertext performers.

Hypertext Condition	Performance	Time	Score	Clicks	Secs. Per Page	Navigation Summary	Interpretation
Structured Hypertext	Highest	Low	26	31	105	- Visited each page and hyperlink at least once. - Spent first 5 minutes visiting multiple pages before returning to the first page.	- Initial familiarisation period helped reader build organisational representation. - Returning to pages prevented missed hyperlinks.
	Lowest	High	10	17	182	- Did not visit 7 pages. - Largest proportion of time spent on first 4 pages. - Had spent over half of their reading time on 2 pages.	- High time pressure meant reader prioritised information that appeared first, and were unable to manage their time effectively.
	Highest	Mod.	25	34	146	- Visited each page at least once. - Had visited all pages within first 10 minutes.	- Initial familiarisation period beneficial for comprehension.
Networked Hypertext	Lowest	High	8	53	102	- Did not visit 3 pages. - Made many clicks, not spending very long on each page.	- Short pages visits meant there was not enough time to engage in deep comprehension processes such as inference-making. - High time pressure meant reader was unable to manage time effectively.

Table 5.19

Overview of navigation activity following five-minute warning prompt.

Hypertext Condition	Performance	Navigation Following 5-Minute Prompt
Structured Hypertext	Highest	- Number of clicks increased. - Navigated to one previously read page and spent remaining time reading it.
	Lowest	- Number of clicks increased. - Navigated to multiple previously read pages rather than clicking new hyperlinks.
Networked Hypertext	Highest	- Following the prompt, navigated through the text to find any hyperlinks that had not been clicked. - Located the one hyperlink that had not been clicked and spent remaining time reading the page it took them to.
	Lowest	- Spent remaining time on the final 3 pages of the text. - Continued reader the text ‘in order’ rather than go back and revisit pages earlier in the chronology of information.

5.6 Discussion

The present study explored how students learn from and navigate through hypertext under different amounts of time pressure. It investigated the differences between print and digital text learning by measuring the navigation, comprehension, working memory, and metacognitive experience of readers of print text, scrolling text, structured hypertext, and networked hypertext. The main findings related to these measures will be discussed in this section. In addition, potential methodological limitations will be considered and directions for future research in this area will be recommended. Implications of these findings will be discussed in more detail in Chapter 8. Table 5.20 includes a brief summary of the main findings of this experiment.

Table 5.20

Study 2 results summary.

Variable	Key Findings
Time Pressure	- High time pressure had a negative impact on integration comprehension. - Interaction effects indicated advantage for readers of scrolling text under no time pressure, but disadvantage for readers of hypertext.
Reading Comprehension	- Print and scrolling text readers performed better on overall, textual, and comprehension measures better than both structured and networked hypertext readers.
Metacognition	- Underconfidence of performance across all groups. - Print and scrolling text readers had the highest JoLs and confidence ratings.
Working Memory	- Both verbal and visuospatial working memory positively correlated with overall and textual comprehension.
Predictions, Interest, Engagement	- Pre and post-test predictions correlated with final comprehension performance across each group.
Reading Strategies	- Participants in each condition reported similar reading strategies. - Most preferred strategy was to memorise as much as possible, whereas least preferred was to become familiar with text layout.
Navigation	- Negative impact of high time pressure on hypertext navigation.

5.6.1 Comprehension

The comprehension results support others' findings that there is a disadvantage for learning from hypertext over print text. A previous experiment presented in this thesis, Study 1 (see Chapter 4), found that there were no differences in textual comprehension scores. Therefore, the present study adapted the reading comprehension test to measure both textual and integration comprehension, as it was predicted that differences between study media may be a result of challenges of developing deep comprehension in hypertext. This study found a disadvantage of hypertext for overall, textual, and integration comprehension. These results the results are consistent with others' findings that show hypertext inhibits the kind of deep processing necessary to answer integration comprehension items. An explanation for this may be that the absence of an explicit organisational structure in hypertext meant readers became disorientated while navigating, leading them to miss information and develop an incomplete situational model.

5.6.2 Time Pressure

This study investigated the effect of time pressure on learning across study media. Previous research has found that high amounts of time pressure have a negative relation to reading comprehension when learning from both digital and print texts (Ackerman & Lauterman, 2012; Gilbert et al., 1993; Kellogg et al., 1999; Thiede & Kürschner, 2007; Tullis & Benjamin, 2011). One explanation for this is that learners who are thinking more about the study time have increased cognitive load which may reduce performance. Another explanation is that greater time pressure inhibits readers' ability to regulate their own learning and engage in more effortful cognitive processes necessary for gaining a deeper comprehension.

Conversely, moderate time pressure has been positively associated with learning outcomes (Dunlosky & Thiede, 2004; Henderson et al., 2007; Kellogg et al., 1999; Walczyk et al., 1999; Wu & Xie, 2018). This may be because moderate time pressure helps readers focus their attention and inhibit the processing of distracting or irrelevant information. The present study predicted that participants learning under high time pressure would perform worse on integration comprehension items than those under moderate and no time pressure. In addition, it was predicted that high time pressure would have the greatest effect on integration comprehension for readers of hypertext, who are already disadvantaged due to the additional processing demands of this type of text.

There were no main effects of time pressure on comprehension scores across study media. However, for those reading under no time pressure, participants were more efficient in their use of time (points per minute) in the print text condition. This supports others' findings that individuals are more efficient in their use of time when learning the same text presented on paper rather than screen (Dillon, 1992; Kerr & Symons, 2006). An explanation may be that print text readers are better able to monitor their learning and make more accurate judgements about how long to spend reading particular information than those reading hypertext. Print text readers do not have to expend cognitive resources by processing additional interactive features like hyperlinks, while hypertext readers do.

5.6.3 Role of Working Memory

The present results supported the prediction that under high time pressure, hypertext readers with lower working memory ability would be especially disadvantaged. Evidence for this is that hypertext readers with lower working

memory ability had lower comprehension scores than higher working memory readers under high time pressure. In particular, high time pressure had a negative impact on the comprehension of hypertext readers with lower visuospatial working memory ability An explanation for this is that these readers quickly became overburdened by processing hyperlinks and identifying structure, so when time constraints were also imposed, they did not effectively process the location of information, and both textual and inferential comprehension suffered.

5.6.4 Metacognitive Experience

The present study found that participants' pre-test comprehension scores were correlated with their actual test scores. Those reading under no time pressure gave the largest range of pre-test and post-test comprehension score predictions. This was expected given the variability of how learners used their study time, evidenced by log file information. Across all reading conditions, participants were generally underconfident in their question responses. This challenges others' findings that screen learners tend to be overconfident in their predictions (Ackerman & Goldsmith, 2012). An explanation for this may be that the sample of Psychology undergraduates were unfamiliar with the historical text, which also had a high reading difficulty score. Therefore, they may have been underconfident because the text itself was challenging. This is supported by the finding that participants across all conditions reported that their interest in the topic was low and that they had to recruit large amounts of mental effort in order to read and understand the text.

The study also found that there were no differences in self-reported mental effort recruited to complete the task between study media or time pressure conditions. This challenges Ackerman and Goldsmith's (2011) findings which

suggest that studying digital texts under high time pressure leads to a recruitment of extra mental effort necessary to reach comprehension scores comparable to those studying print texts. Similarly, while Salmeron and colleagues (2018) found equivalence in learning outcomes across study media, their study indicated that learners may recruit extra cognitive resources including mental effort in order to overcome the disadvantage of reading on-screen. A future study might use a text topic that participants are familiar with and explore whether there are any effects of study media on mental effort. Furthermore, the mental effort questionnaire item could be refined to better measure how effortful *learning* the information was, as opposed to how effortful *reading* the text was. This distinction would allow for a more valid measure of how much additional cognitive effort participants have to recruit to facilitate learning across study media.

5.6.5 Individual Differences in Navigation Behaviour

Log files were examined to explore hypertext readers' navigation behaviour; how they used the reading time, what information they accessed, and in what order. Similar to the navigation results of Experiment 1 (see Chapter 4), networked hypertext readers visited more pages and spent less time on average per page than those reading structured hypertext. Others have found students have difficulty navigating hypertext due to its complex structure (Bayazit et al., 2018; Blom et al., 2018; Cangoz & Altun, 2012; Shapiro & Niederhauser, 2004). The networked hypertext contained a greater number of hyperlinks and connections between pages, adding to its complexity. In addition, readers of both structured and networked hypertext missed several pages. An explanation for this could be that some hypertext readers did not have a clear navigation strategy.

Previous research has suggested that low working memory ability readers may find it difficult to apply learned strategies to reading hypertext (Amadieu et al., 2009; Naumann et al., 2008; Salmerón & García, 2011). The reading strategies questionnaire found that a high proportion of participants reported that they tried to find connections between different parts of the text. This supports the claim that readers attempt to build a coherent mental representation of a text to understand it better. However, the complexity and non-linearity of hypertext may mean it is difficult for readers of to do this. One way of overcoming the 'missed pages' phenomenon would be to introduce a graphical overview to facilitate readers' construction of a mental representation by showing how pages are interconnected. Therefore, a future study could explore the effect of a graphical overview on students' comprehension and navigation of hypertext.

It was predicted that there would be differences in the navigation behaviour of those reading under different levels of time pressure. However, there was no effect of time pressure on time spent per page, number of clicks, or page visits for structured or networked hypertext readers. However, networked hypertext readers missed more pages. This may be because the structure of this type of text is more complex, with greater number of hyperlinks adding to the difficulty of finding unread navigation routes. This is supported by the fact that networked hypertext readers reported greater disorientation and feelings of getting lost while navigating through the text. Further support for this is that lower visuospatial working memory ability readers were especially disadvantaged in networked hypertext.

5.6.6 Implications and Directions for Future Research

The findings from this study contribute to the 'paper versus screen' debate. The results support the theory that the kind of deep processing involved in integrating information from multiple sections of a text is impaired when learning through hypertext. This is partly due to broader impairments in the metacognitive regulation of learning on-screen. Evidence for this is that readers of hypertext were the most inaccurate at evaluating their own learning. Moreover, the results showed that readers of hypertext were especially disadvantaged when learning under greater time pressure, and that visuospatial working memory is related to better textual and inferential comprehension across both digital and print texts.

Another factor that may impact learning across study media is how much knowledge the reader already has about the text topic. For example, Ozuru and colleagues (2009) investigated how text features (such as cohesion) and individual differences (reading skill and prior knowledge) contribute to scientific text comprehension. They found that reading a high-cohesion text improved text-based comprehension, and that overall comprehension was positively correlated with participants' prior knowledge. Similarly, Calisir and Gurel (2003) also explored influence of text structure and prior knowledge of learners on reading comprehension across linear (traditional print text) and non-linear texts (hierarchical hypertext, mixed hypertext). In the present study, participants had little to no prior knowledge of the given topic. Therefore, a future study could investigate the effect of study media on the comprehension and navigation of both low and high prior knowledge participants.

Chapter 6: Experiment 3 – The Effect of Prior Knowledge on Navigation and Comprehension in Hypertext

This chapter will describe the third in a series of empirical experiments which assess how students learn from and navigate through hypertext, as well as the differences between paper and screen learning. The primary focus of Study 3 will be to explore the effect of prior knowledge on learning across study media. Furthermore, it will assess the effect of print versus digital learning on different levels of comprehension. Some of the methodology used in this experiment is similar to that used in Study 1 (see Chapter 5) and Study 2 (see Chapter 6), so the methodology section of this chapter will only detail that which has not previously been described in an earlier chapter. In addition, relevant background information has also been described previously (see Chapters 1-3), so only new information related to the present experiment will be presented in this chapter.

6.1 Background

6.1.1 Prior Knowledge: Relation to Comprehension

One way in which readers try to make sense of what they are reading is by making connections between the text and what they already know, called prior knowledge. Prior knowledge is sometimes specified in the literature as prior domain knowledge, which is all information a person possesses about a particular field of study (Alexander & Jetton, 2000; Lawless & Kulikowich, 2006). Both prior knowledge and domain knowledge have been consistently positively correlated with higher learning outcome scores in reading tasks and are considered important for comprehending texts (Amadieu et al., 2010; Alexander, 2003; Kintsch, 1988; Lawless et al., 2007). Less is known about the effects of prior knowledge on

different types of comprehension across study media. Therefore, the present study will assess the comprehension of low and high prior knowledge readers of print and digital texts.

Prior knowledge has been found to be useful for helping print text readers to orient their attention towards more relevant information, and accurately refute false assertions (Kendeou et al., 2014; Richter, 2009). However, results have been more inconsistent for digital texts; some studies suggest that there is no relationship between prior knowledge and learning from digital texts, especially for high prior knowledge readers (Chen & Macredie, 2010; Sullivan & Puntambeker, 2017). Whereas, others have found that low knowledge readers have increased feelings of disorientation and weaker comprehension when learning from hypertext (Amadieu et al., 2015; Amadieu et al., 2010). The present study will explore the relationships between prior knowledge, working memory, metacognitive experience, and hypertext learning and navigation.

6.1.2 Prior Knowledge: Relation to Hypertext Navigation

Learning from hypertext requires integration of information from different locations, the formation of semantic relationships between information parts, and the maintenance of coherent reading pathways (Madrid et al., 2009; Salmerón et al., 2005). Moreover, processing hypertext requires readers to fill in information gaps and to self-regulate their learning (e.g., when selecting links or remembering their pathways). These necessary processes may be challenging for learners, especially those with low prior knowledge. This is because low knowledge readers are unable to fill in coherence gaps with information they already know about the topic.

Therefore, it might be expected that these readers would have a disadvantage for reading from hypertext in comparison to high knowledge readers whose deep inferential activity is triggered by the coherence gaps imposed by the hypertext. For example, previous research has found that only highly skilled readers are less affected by these challenging tasks when learning from hypertext (Naumann et al., 2007; Salmerón & García, 2011). Low prior knowledge readers may have to recruit additional cognitive resources when navigating hypertext to ensure they do not miss any information and can recall the location of links. This is because they may not be able to fill in cohesion gaps with previously learned information, meaning they must construct mental representations based on the current information alone. The present study will explore the comprehension and navigation of low and high prior knowledge readers across study media, and builds on previous studies by also considering factors such as working memory, metacognitive experience, and reading strategies.

6.2 Aims and Hypotheses

An experiment was conducted with the aim of investigating the effect of prior knowledge on students' navigation and learning of hypertext. It also explored the differences between print and digital text learning. The relationships between working memory, navigation behaviour, reading strategies, and metacognitive experience were assessed for readers of print text, scrolling text, and hypertext. It sought to address the following hypotheses:

H_1: Print text readers will score significantly higher on a comprehension test versus readers of scrolling text and networked hypertext.

H_2: There will be a significant main effect of prior knowledge on overall comprehension test scores, with those in the high prior knowledge group performing significantly better than those in the low prior knowledge group.

H_3: Low prior knowledge hypertext readers will have significantly weaker integration comprehension test scores than high knowledge hypertext readers.

6.3 Method

Measures retained in this experiment which have been previously described in earlier chapters include PIEpre and PIEpost questionnaires, verbal and visuospatial working memory tests, and metacognitive items (see Chapters 4-5). Materials which are either new or have been adapted from previous experiments include the text, reading comprehension test, familiarity questionnaire, and reading strategies questionnaire.

6.3.1 Design

This study made use of a between-subjects experimental design in which 52 participants were assigned to either one of the following three reading conditions: print text (N = 18), scrolling text (N = 17); or networked hypertext (N = 17). Structured hypertext was dropped for this experiment because previous experiments (see Chapters 4-5) had found similar findings for both structured and networked hypertext. This experiment sought to focus on one type of hypertext, and since the networked format is considered the most complex (and in need of further investigation), it was retained. Participants were designated as either low prior knowledge (N = 39), or high prior knowledge (N = 13). This resulted in participants being placed into one of six conditions (see Figure 6.1 for overview of reading conditions).

Participants read an informational text and completed questionnaires during one 60-minute testing session. This text was different from the one used in previous experiments (Chapters 4-5) because the aim of this experiment was to explore prior knowledge. Therefore, a new text about a psychology topic was introduced so that students could be grouped as either high or low prior knowledge (Appendix B). In addition, it was hoped that a new text would support the generalisability of findings to a range of reading contexts. The texts were designed to look like informational texts students might encounter when engaging with educational resources either in a textbook or online. Participants were randomly assigned, and blinded to, their conditions. Table 6.2 gives a brief description of each reading text condition (see Chapter 1 for more detailed descriptions of different types of hypertext).

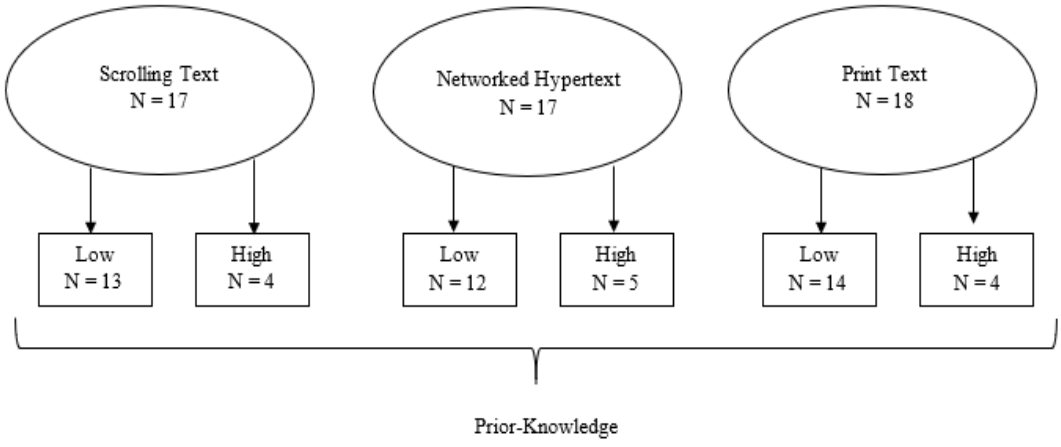


Figure 6.1. Overview of conditions.

Table 6.2

Descriptions of each reading text condition.

Reading Condition	Description
Print Text (*N* = 18)	Text printed out onto paper. All 12 sections presented in chronological order and separated by section headings.
Scrolling Text (*N* = 17)	Text appears on screen with the 12 sections presented in chronological order. Readers must scroll down the block of text using either mouse wheel or scroll bar. No hyperlinks. A 'back to top' button allows reader to immediately navigate to the top/beginning of text.
Networked Hypertext (*N* = 17)	Text presented on screen with 12 individual webpages, each page being a section of the text. All readers open the webpage on the first section of the text and may navigate to other sections by clicking on blue underlined hyperlinks (total = 28). Hyperlinks may take the reader to any section along the chronology of information (e.g. from the introduction section to the battle conclusion section). A 'back to previous page' button allows reader to return to the previous section.

The graphical structure of the networked hypertext condition can be seen in Figure 6.3. Within this figure, each square represents an individual page of the website, with the page number inside (e.g. page 1.0 = 1.0). Furthermore, each arrow represents a navigation decision presented in the text as a hyperlink. Some pages have several arrows pointing to other pages, representing when the reader must decide whether to click one of several hyperlinks to navigate away from the current page.

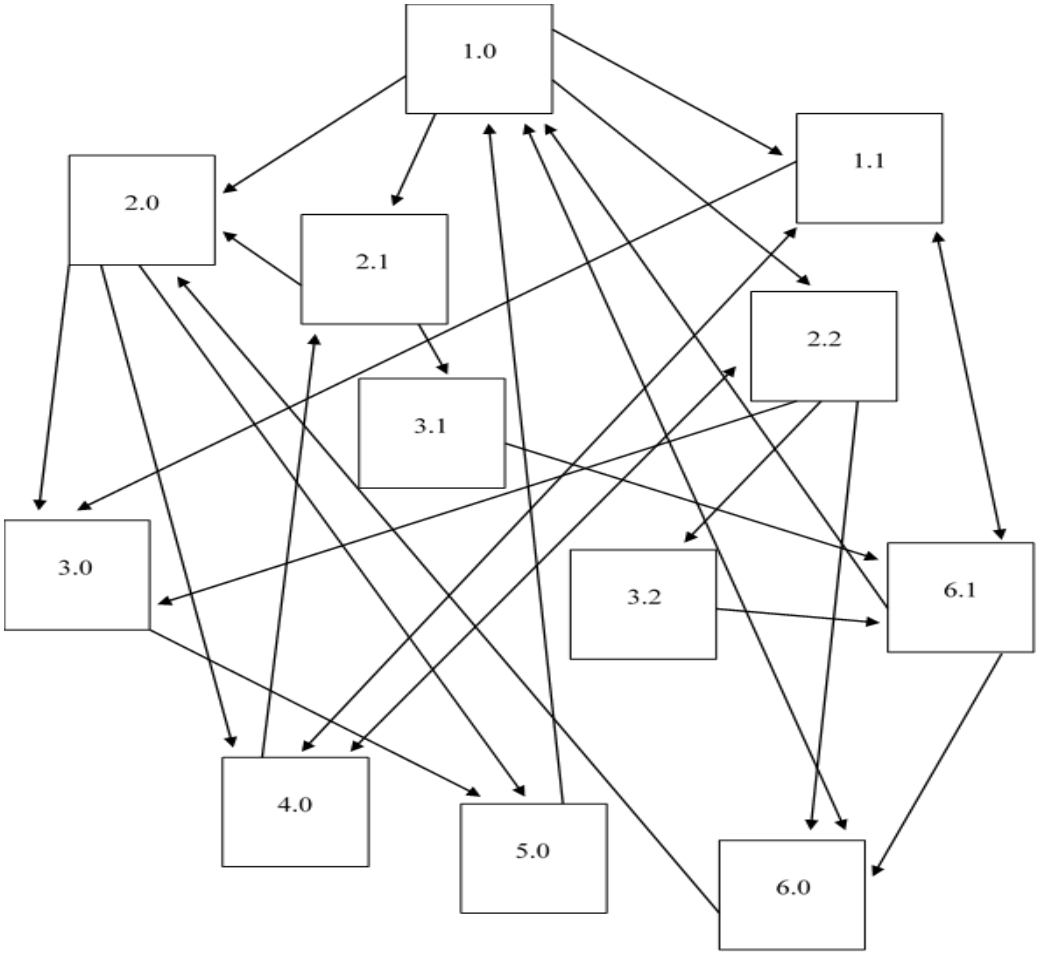


Figure 6.3. Overview of Networked Hypertext, with page numbers.

The information necessary to correctly answer the 20 comprehension test questions was distributed across the 12 sections of the text. For the print text and scrolling text conditions, this means that the answers are distributed across the 12 sections separated by section headings. For instance, in order to be able to answer questions 10 and 18 correctly, participants must recall information located in the 'The Phonological Loop' section, which was labelled as section 2.1. In the networked hypertext condition, this means that answers are distributed across the 12 individual pages of the website. Information required to answer integration questions was found on multiple pages. For instance, in order to be able to answer question 17 correctly, participants must recall information located on pages 1.0, 1.1,

and 6.0. The comprehension questions were distributed across the sections of the text so that: five questions were assigned to sections 1.0, 3.1, and 5.0; four questions were assigned to sections 1.1, 2.0 and 3.2; three questions were assigned to section 6.1; two questions were assigned to sections 2.1, 2.2 and 6.0; no questions were assigned to section 3.0.

6.3.2 Participants

The study consisted of a sample of 52 healthy participants, recruited from the university campus via an online study recruitment program or by email advertisement. There were 11 males (21.2%) and 41 females (78.8%), ranging between 18 and 34 years of age (M = 20.96, SD = 4.39). Individuals who responded to the experimenters were allocated a timeslot to participate. Low prior knowledge participants were first-year undergraduate students in psychology, whereas high prior knowledge participants were either third-year psychology undergraduates, psychology postgraduates, or psychology PhD students with experience of studying the topic of working memory and related concepts. Low prior knowledge participants who successfully completed the study received 60 participation credits; high prior knowledge participants received five pounds for taking part. Participants were not subject to any exclusion criteria.

6.4 Measures and Materials

6.4.1 The Text

Each participant read the same informational text, regardless of which of the three text conditions they were in. Information contained within the text consisted of 2580 words based on the topic of working memory and related concepts, edited from information gathered from psychology textbooks, online resources and academic

papers. In total there were 12 sections with an average word count of 215 (*SD* = 28.13) words, 40 paragraphs in total, and an average of 21.5 words per sentence.

Readability tests were conducted on the whole text to assess its suitability for the expected sample of undergraduate and postgraduate psychology students. Anything above the Flesch-Kincaid reading ease score of 30.0 is considered suitable to be read by university students (Flesch, 1948). The text had a Flesch-Kincaid Reading Ease score of 31.6, and a Flesch-Kincaid Grade Level of 13.9 meaning that while the text can be considered 'difficult' to read, it is suitable to be read by senior high school and university students. Analysing each page individually, there was a readability range of 45.6 (*min.* = 9.5, *max.* = 55.1) with pages 1.0, 5.0 and 2.1 being the most difficult sections of the text to read, with readability scores of 9.5, 9.8, and 12.0 respectively. These readability scores meant that the sections were considered very difficult to read and were most suited for university graduates. Therefore, all sections were suitable to be read for the education level of the participants.

As previously stated, the text was divided into 12 sections, each providing new information with its own section heading. In the print text condition, the text was printed with each section following on from each other, separated by section headings. In the scrolling text condition the text appeared on-screen as a block of text, with each section separated by section headings. In the networked hypertext condition, each of the 12 sections had its own individual page with section headings. For analysis and visualisation purposes the sections were designated page numbers, however these were unknown to participants. Several sections had a small accompanying picture appearing on the right-hand side of the page/screen. The picture was something related to the section such as an image of a brain, and sections

relating to individuals had a picture of the person themselves. Table 6.4 shows information about each section of the text including section titles, word count, and readability information.

Table 6.4

Information about each page of the text including readability statistics.

Page	Title	Links	Word Count	Paragraphs	Lines	F-K Reading Ease	F-K Grade Level
1.0	Working Memory: A Background	4	212	2	18	9.5	18.5
1.1	Patients with Brain Impairments	3	246	2	19	31.6	13.9
2.0	The Central Executive	3	242	3	14	39.7	11.5
2.1	The Phonological Loop	2	200	2	17	12.0	17.0
2.2	The Visuospatial Sketchpad	4	237	2	17	45.3	12.0
3.0	Long-term Memory	1	224	2	18	36.0	11.9
3.1	Testing the Phonological Loop	1	209	1	15	35.1	13.1
3.2	Testing the Visuospatial Sketchpad	1	236	1	16	55.1	11.0
4.0	The Episodic Buffer	3	147	2	12	18.1	19.8

Page	Title	Links	Word Count	Paragraphs	Lines	F-K Reading Ease	F-K Grade Level
5.0	The Embedded Processes Model	1	218	6	20	9.8	16.9
6.0	Evaluating the Working Memory Model	3	183	2	15	30.8	14.0
6.1	The Dual-Task Experiment	2	224	5	20	22.5	14.4

6.4.2 Comprehension Test

Reading comprehension performance was assessed through a test consisting of 20 items. This comprehension test was different from the one used in previous experiments because it assessed the learning of the new text. Another way in which this comprehension test differed is that there were an equal number of textual and integration items; 10 multiple-choice items with four options assessed textual comprehension (e.g., 'Who first proposed a multicomponent theory of working memory?'), and 10 items that assessed integration comprehension (e.g., 'Which of the components of working memory do you think is the most important? Why?'). Some integration items were multiple-choice, whereas others required short-answers. Both question types were considered a valid measure of integration comprehension because they required participants to synthesise information found throughout the text and to make inferences based on their own prior knowledge. While the short-answers were more difficult to score due to the variability in the quality and length of answers, consistency of marking in line with the definition of integration

comprehension improved the reliability of this measure. All 20 items were scored as either correct (1) or incorrect (0).

Also on this questionnaire were confidence ratings, where participants indicated on a percentage scale the certainty that they had answered each of the 20 questions correctly ranging from certain they had answered it incorrectly (0%) to certain they had answered it correctly (100%). Confidence ratings were recorded immediately after answering each of the 20 items.

6.4.3 Familiarity

In the experiment, participants were designated as either being 'high prior knowledge', or 'low prior knowledge' in the topic of working memory. High prior knowledge participants were recruited from either third-year undergraduate or postgraduate students in psychology and were expected to have had more familiarity with the topic of working memory and related concepts throughout their time in academia. Low prior knowledge participants were first-year psychology students who were expected to have low familiarity with working memory.

A nine-item familiarity questionnaire was administered to assess how familiar the participants were with each of the topics mentioned in the informational text used in the reading task. Participants responded to eight items such as 'How familiar are you with the phonological loop of working memory', and 'How familiar are you with the background to the conception of working memory?' on a six-point scale ranging from 'Completely Unfamiliar', to 'Very Familiar'. The final familiarity item asked how much time participants spend per week reading information from the following: online for leisure; print text for leisure; online for university work; print text for university work; hypertext. This item was rated as

either: 1, ‘less than one hour’; 2, ‘one to three hours’; 3, ‘four to six hours’; 4, ‘seven to ten hours’; or 6, ‘more than ten hours.’

6.4.4 Reading Strategies

The self-reported reading strategies that participants said they used while navigating through the text were assessed through a reading strategies questionnaire consisting of 20 items. The two previous experiments that used a reading strategies questionnaire identified difficulties in relating responses to navigation and comprehension across study media, and found no differences between groups. Therefore, a new reading strategies questionnaire was developed to include items more explicitly related to navigation. Items which allowed for comparison between study media were retained.

Participants indicated on a six-point scale ranging from ‘Completely Disagree’ to ‘Completely Agree on 12 statement items such as ‘I tried to find connections between the different parts of the text’, ‘I revisited sections containing information I found difficult to remember’, and ‘I found it easy to distinguish between the beginning, middle, and end of the text’. The remaining eight items included statements related to how participants engaged with the text with options to choose from, including ‘Once I was sure I had read all of the sections of the text I…’, as well as some items only relevant to those reading from hypertext such as, ‘When I encountered a hyperlink I…’.

6.5 Procedure

1) Low prior knowledge participants (first-year psychology undergraduates) responded to the study advert on the university’s online participation system and signed up to an available timeslot. High prior knowledge

participants (third-year undergraduate and postgraduate psychology students) responded to a study advert email and arranged a testing session. After arriving in the test lab, participants read through the study information sheet which gave some brief information about the background of the experiment. They were then invited to provide their informed consent before taking part in the experiment.

2) Participants were firstly asked to complete a series of working memory tasks lasting approximately 20 minutes including; a visuospatial-span task involving correctly tapping a sequence of blocks in forward and reverse order (10 minutes); and a verbal working memory span task involving the recollection of a series of animals verbalised by the experimenter in forward, reverse, and size order (10 minutes). Next, they completed the PIEpre questionnaire which lasted around two minutes followed by the familiarity questionnaire (two minutes).

3) Participants were then randomly assigned to one of three reading conditions: print text, scrolling text, or networked hypertext. In total, a participant could be placed into one of six conditions. Participants were told that they would read an informational text on the topic of working memory for 20 minutes in preparation for a comprehension test, and that the experimenter would let them know once these 20 minutes have ended. Using PC logging software, some reading navigation information was recorded for those in the hypertext condition. Participants were not aware during the reading task that their navigation behaviour was being recorded.

4) Following the completion of the reading task, participants completed the remaining questionnaires which took approximately 20 minutes to complete. Firstly, they were given the comprehension test where they answered 20 questions

related to the text. This questionnaire consisted of 10 textual items related to exact information located in the text, and 10 integration items which required the synthesis of knowledge across multiple sections and for the participant to form an argument based on this information. They also provided confidence ratings by indicating on a percentage scale the certainty that they had answered each of the 20 questions correctly, ranging from certain they had answered incorrectly (0%), and certain they had answered it correctly (100%). The PIEpost questionnaire was subsequently administered (two minutes), before finally completing the reading strategies questionnaire (five minutes). Participants were invited to read and sign the debrief form and there was an opportunity at the end of the test session for them to ask any questions about the experiment.

6.6 Results

This section will begin with the familiarity questionnaire, as this measure was important in determining whether low and high prior knowledge participants were appropriately grouped (i.e., according to the amount of knowledge they had about working memory and related concepts). Results related to reading comprehension, working memory, confidence ratings, PIE, reading strategies, and navigation will be presented, in addition to integrative analysis assessing the comparative impact of each measure on comprehension.

6.6.1 Familiarity

Overall, participants reported that they were most familiar with the broad topic of working memory (M = 3.15), and least familiar with the Embedded Processes Model (M = 1.90). They generally spent at least four to six hours reading online for leisure versus one to two hours reading print text for leisure, and between

one to three hours reading print text and online for university work. They also reported that they spent one to three hours per week reading from hypertext. There were no significant differences between prior knowledge or reading text conditions on how long per week participants spent reading from print, online, or hypertext, for either leisure or university work. Table 6.5 shows the descriptive statistics for all nine items of the familiarity questionnaire across each condition.

Table 6.5

Average ratings for familiarity questionnaire items, overall and across each text condition.

Question Number	Description	Overall	Text Condition		
			Print	Scrolling	Hypertext
1	WM	3.15	2.89	3.47	3.12
2	Background	2.71	2.72	2.71	2.71
3	CE	2.56	2.50	2.71	2.47
4	PL	2.38	2.33	2.59	2.24
5	VSS	2.38	2.28	2.65	2.24
6	Episodic B.	2.17	2.28	2.12	2.12
7	Emb. Pro.	1.90	1.94	1.82	1.94
8	LTM	3.08	2.89	3.24	3.12
9	Online	3.42	3.56	3.53	3.18
	Print	2.52	2.78	2.12	2.65
	Uni Online	2.44	2.39	2.59	2.35
	Uni Print	2.25	2.06	1.94	2.76
	Hypertext	2.33	2.78	2.35	1.82

A two-way between subjects MANOVA was conducted to assess the effect of reading condition and prior knowledge on each of the familiarity questionnaire items. There was no significant main effect of text condition on familiarity ratings, $F(26, 68) = 1.41$, $p = .131$, partial $\eta^2 = .343$, but there was a significant main effect of prior knowledge, $F(13, 34) = 5.94$, $p < .001$, partial $\eta^2 = .694$. As expected, those in the high prior knowledge group rated their familiarity of each of the topics presented in the text as significantly higher than those in the low prior knowledge group ($p < .001$). The results were not modified by an interaction effect ($p = .451$). These results are summarised in Table 6.6.

Table 6.6

Results of MANOVA assessing effect of reading condition and prior knowledge on topic familiarity.

Groups/Interaction	Effect on Overall Familiarity Scores	
	F	*p*
Reading Condition (RC)	1.41	.131
Prior Knowledge (PK)	5.94	**< .001***
RC*PK	1.72	.451

***** significant at $p < .05$.

6.6.2 Reading Comprehension

Overall, reading comprehension test scores had a range of 12 (*min.* = 6, *max.* = 18), with a mean score of 12.15. The textual questions had a mean score of 6.87, and the integration questions had a mean score of 5.23. The greatest range of scores was found in the print text condition, wherein the lowest score was 6 and the highest score was 18. There was 60.8% overall comprehension accuracy; 69.7% accuracy in

the print text condition; 62.6% accuracy in the scrolling text condition; and 49.4% in the structured hypertext condition. The means for each condition are shown in Table 6.7. Reliability analyses of the reading comprehension test questions showed a sufficient Cronbach's alpha for both the textual (α = .69) and integration items (α = .70).

Overall Scores. To test the hypothesis $\mathbf{H_1}$ (that print text readers will perform significantly higher on comprehension versus readers of scrolling text and hypertext) and $\mathbf{H_2}$ (that participants who are high in prior knowledge will score higher on comprehension than those with low prior knowledge), a two-way between subjects ANOVA was conducted to assess the effect of reading condition and prior knowledge on overall comprehension test scores. In support of $\mathbf{H_1}$, there was a significant main effect of reading condition on overall test scores, $F(2, 46) = 6.46$, $p = .003$, partial $\eta^2 = .219$. Tukey's post-hoc tests found participants in the both the print ($p = .001$) and scrolling text ($p = .033$) reading conditions performed significantly better than those in the hypertext condition. There was no significant difference between scores of those in the print text and scrolling text conditions ($p = .204$).

In support of $\mathbf{H_2}$, there was a significant main effect of prior knowledge on overall comprehension test scores, $F(1, 46) = 8.02$, $p = .007$, partial $\eta^2 = .148$. Those in the high prior knowledge group performed significantly better than those in the low prior knowledge group ($p = .007$). There was no interaction effect of text condition and prior knowledge ($p = .904$).

Textual Scores. A two-way ANOVA was conducted to examine the effect of reading condition and prior knowledge on correct responses for the 10 textual

comprehension items. While there was no significant main effect of reading text condition on textual item scores, $F(2, 46) = 6.46$, $p = .643$, partial $\eta^2 = .019$, there was a significant effect of prior knowledge, $F(1, 46) = 4.45$, $p = .040$, partial $\eta^2 = .088$. Tukey's post-hoc test found those in the high prior knowledge group performed significantly better on textual items than those in the low prior knowledge group ($p = .040$).

Integration Scores. To test the hypothesis **H_3** (that hypertext readers would score lower on integration comprehension than scrolling text and print text readers), a mixed ANOVA was conducted to examine the effect text condition and prior knowledge on correct responses for the 10 integration comprehension questions. There was a significant main effect of text condition on integration item scores, $F(2, 46) = 12.24$, $p < .001$, partial $\eta^2 = .347$. Tukey's post-hoc test found those in the print ($p < .001$) and scrolling ($p = .004$) text conditions performed significantly better on integration items than those in the hypertext condition. There was also a significant interaction effect of prior knowledge on integration item scores, $F(1, 46) = 7.32$, $p = .010$, partial $\eta^2 = .137$, with the high prior knowledge group performing significantly better on integration items than the low prior knowledge group ($p = .010$).

Table 6.7

Overall, textual, and integration comprehension scores across all conditions.

Comprehension	PK	Overall		Text Condition					
				Print		Scrolling		Hypertext	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	11.54	3.58	13.36	3.88	12.00	2.86	8.92	2.35
	High	14.00	2.74	16.00	2.16	14.25	1.71	12.20	2.95
Textual	Low	6.59	1.81	6.79	1.81	6.92	1.19	6.00	1.35
	High	7.69	1.19	8.00	2.16	7.50	1.73	7.60	2.51
Integration	Low	4.87	2.61	6.57	2.44	5.08	2.25	2.67	1.37
	High	6.31	1.80	8.00	.00	6.75	1.71	4.60	.89
Range (min. – max. score)		12 (6-18)		12 (6-18)		9 (7-16)		9 (6-15)	

6.6.3 Working Memory

Analyses were conducted to test the relationships between working memory and comprehension across study media and prior knowledge. Since there was a significant positive correlation between verbal span and raw scores, $r(52) = .913$, $p < .001$, and visuospatial span and raw scores, $r(52) = .853$, $p < .001$, only verbal and visuospatial raw scores will be reported.

Verbal Working Memory

Performance on the verbal working memory test (scored as previously described) was best for forwards order ($M = 7.69$, $SD = 1.50$), and weakest for

reverse order (M = 5.06, SD = 1.27). There were no significant differences in, or verbal raw scores, $F(2, 46) = .678$, $p = .513$, partial $\eta^2 = .029$, between text groups. There were also no differences between prior knowledge groups, $F(1, 46) = 3.012$, $p = .089$, partial $\eta^2 = .061$. Therefore, each group included participants of similar verbal working memory ability. The descriptive statistics for the verbal working memory test are shown in Table 6.8.

Table 6.8

Descriptive statistics for each task of the verbal working memory test across all groups.

		Print		Scrolling		Hypertext	
		M	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	18.07	2.62	17.92	3.09	18.08	2.27
	High	20.50	2.38	18.75	2.36	19.20	2.17
Forward	Low	7.00	.78	7.46	1.33	7.33	1.15
	High	8.25	1.50	7.75	1.26	7.80	1.10
Reverse	Low	5.07	1.44	4.92	1.26	4.67	1.30
	High	6.00	1.63	5.75	.96	5.60	1.82
Sequencing	Low	6.00	.96	5.54	1.45	6.08	.67
	High	6.25	.50	5.25	.96	5.80	.84

Pearson's correlations which assessed the relationship between participants' total verbal working memory raw scores (max. = 48) and how many correct answers they gave on the comprehension test (max. = 20) across each group, found a significant positive relationship between total verbal working memory scores and

test scores across all reading conditions, $r(52) = .292$, $p = .035$. The greater participant's working verbal memory, the higher their score on the reading comprehension test.

Further correlations assessed the relationships between participants' verbal working memory raw scores (max. = 48) and how many total correct answers they gave on the 10 textual and 10 integration items of the comprehension test across all three reading conditions, finding a significant relationship between total verbal working scores and textual item scores, $r(52) = .366$, $p = .008$. The greater participants' verbal working memory, the higher they scored on the textual comprehension test items. However, there was no relationship between verbal scores and integration comprehension.

Correlations which assessed the relationship between verbal working memory and comprehension for each text group found that the verbal working memory of those in the print text condition was positively correlated with overall, textual, and integration comprehension (Table 6.9).

Table 6.9

Correlations between verbal working memory and comprehension for each condition.

Condition/Comprehension	Overall		Textual		Integration	
	r	*p*	*r*	*p*	*r*	*p*
Print	**.600**	**.009***	**.590**	**.010***	**.492**	**.038***
Scrolling	.132	.612	.348	.171	-.039	.883
Hypertext	.124	.636	.147	.573	.135	.606

***** significant at $p < .05$.

Visuospatial Working Memory

Performance on the visuospatial working memory test (scored as previously described) was best forwards order (M = 7.85, SD = 1.33), and the weakest for reverse order (M = 7.63, SD = 1.68). There was no significant difference in visuospatial raw scores, $F(2, 46) = .663$, $p = .520$, partial $\eta^2 = .028$, between groups. The same was found for the prior knowledge groups. Therefore, each group included participants of similar visuospatial working memory ability. The descriptive statistics for both trials of the visuospatial working memory task are shown in Table 6.10.

Table 6.10

Descriptive statistics for each trial of the visuospatial working memory test across all groups.

		Print		Scrolling		Hypertext	
		M	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	15.79	2.64	16.54	2.50	14.42	2.07
	High	14.25	2.99	14.75	1.50	16.20	1.79
Forward	Low	8.07	1.07	8.15	1.21	7.33	1.15
	High	7.50	2.08	7.50	.50	8.00	1.22
Reverse	Low	7.71	1.73	8.38	1.76	7.00	1.91
	High	6.75	.96	7.00	1.15	8.20	.84

Pearson's correlations found no significant relationship between visuospatial working memory and overall (p = .834), textual, (p = .578), and integration (p = .478) comprehension scores. Additional correlations assessing the relationship between visuospatial working memory and comprehension for each group separately

found no significant correlations between visuospatial working memory and overall, textual, and integration comprehension for each of the three text conditions.

To summarise the working memory results, a positive relationship was found between verbal working memory and overall and textual comprehension, while there was no relationship between visuospatial memory and comprehension. When looking at each group separately, the verbal working memory of those in the print text condition was positively correlated with overall, textual, and integration comprehension.

6.6.4 Confidence Ratings

The highest average confidence ratings were reported by high prior knowledge participants reading from print text (70.6%), and the lowest were reported by low prior knowledge participants in the hypertext condition (45.3%). The average confidence ratings for participants in each reading condition were compared with their actual performance on the reading comprehension test. In the scrolling and print text conditions, the average confidence ratings by both low and high prior knowledge participants were lower than the actual comprehension performance in these conditions. However, in the hypertext condition, both low and high prior knowledge participants reported higher confidence ratings than their actual performance. This suggests an underconfidence of performance in the scrolling and print text conditions, and an overconfidence for those in the hypertext condition (Figure 6.11).

A two-way MANOVA was conducted the assess the effect of prior knowledge and reading text condition on average confidence ratings. Using Wilks' Lambda, there was no significant main effect of text condition on overall confidence

ratings, $F(40, 54) = 1.16$, $p = .298$, partial $\eta^2 = .463$. Using Wilks' Lambda, there was a significant main effect of prior knowledge on overall confidence ratings, $F(20, 27) = .28$, $p = .001$, partial $\eta^2 = .463$. High prior knowledge participants generally reported higher confidence in their answers than those in the low prior knowledge group.

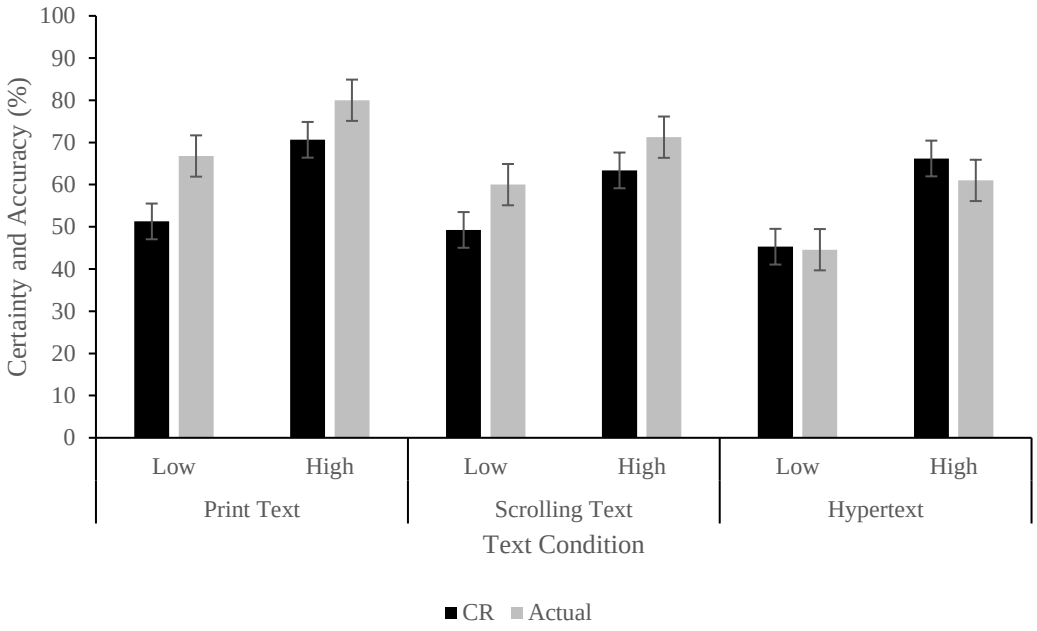


Figure 6.11. Average confidence ratings compared with actual performance accuracy across all text conditions.

6.6.5 Predictions, Interest, and Effort (PIE)

Before taking part in the reading task, participants first completed the PIEpre questionnaire in which they were asked to predict how many answers they would get correct out of 20 on a comprehension test ($M = 12.35$, $SD = 2.80$) and, using a six-point scale, rate their interest in the topic ($M = 4.52$, $SD = 1.13$), predict how difficult it would be to learn the content of the text ($M = 3.65$, $SD = .95$), and how difficult the test questions will be ($M = 3.67$, $SD = .83$). After completing the reading task and the comprehension test, participants completed the PIEpost questionnaire in

which they were asked the same questions. The descriptive statistics for items on the PIEpre and PIEpost questionnaires are displayed in Table 6.12.

Overall, there was a significant positive relationship between participants' pre-test predictions and their final comprehension test scores, $r(52) = .300$, $p = .031$. Similarly, post-test predictions were significantly correlated with their final comprehension test scores, $r(52) = .576$, $p < .001$. Therefore, participants were generally accurate at predicting how many questions they had answered correctly out of 20, before and after having completed the comprehension test.

Table 6.12

Descriptive statistics for PIEpre and PIEpost questionnaire items across all reading conditions.

Measure	Pre/Post	Reading Condition					
		Print		Scrolling		Hypertext	
		M	*SD*	*M*	*SD*	*M*	*SD*
P (0-20)	Pre	12.50	3.30	11.88	2.83	12.12	2.39
	Post	10.94	5.18	10.35	3.50	8.41	4.09
I (1-6)	Pre	4.89	.96	4.35	1.27	4.29	1.10
	Post	4.44	1.34	4.53	.94	3.71	1.31
CD (1-6)	Pre	3.72	.96	3.65	.86	3.59	1.06
	Post	3.78	1.11	3.76	1.30	4.82	1.42
QD (1-6)	Pre	3.89	.96	3.59	.80	3.53	.72
	Post	4.39	1.04	3.88	.99	4.00	1.27

Note. **P** = Prediction; **I** = Interest; **CD** = Content Difficulty; **QD** = Question Difficulty.

A two-way MANOVA conducted to assess whether reading condition and prior knowledge groups differed on PIEpre or PIEpost measures of predictions, interest, content difficulty, or question difficulty, found a significant main effect of prior knowledge on pre-test comprehension score predictions and content difficulty predictions. Those in the high prior knowledge group reported a higher comprehension score prediction than low prior knowledge participants ($p = .011$), whereas those in the low prior knowledge group predicted higher content difficulty than high prior knowledge participants ($p = .010$). A similar pattern was found for post-test comprehension predictions. While post-test comprehension score predictions were lower than their pre-test predictions ($p < .001$), post-test ratings of content difficulty ($p = .024$) and question difficulty ($p = .002$) were significantly higher than their pre-test predictions (Table 6.13).

Table 6.13

Results of two-way MANOVA on PIEpre and PIEpost measures, with t-test.

Measure	Pre/ Post	Main Effects						*t*-test	
		Condition		PK		Condition*PK			
		F	*p*	*F*	*p*	*F*	*p*	*t*	*p*
P (0-20)	Pre	.70	.50	**6.99**	**.011***	.28	.758	4.52	**< .001***
	Post	2.17	.132	**11.23**	**.002***	.28	.757		
I (1-6)	Pre	1.95	.153	2.99	.089	1.26	.291	1.88	.066
	Post	2.54	.090	.94	.338	.49	.616		
CD (1-6)	Pre	.38	.691	**7.19**	**.010***	2.00	.154	2.32	**.024***
	Post	2.22	.121	**4.36**	**.042***	2.39	.103		
QD (1-6)	Pre	.17	.855	.98	.338	1.22	.314	3.19	**.002***
	Post	2.22	.121	2.02	.162	.31	.738		

Note. **P** = Prediction; **I** = Interest; **CD** = Content Difficulty; **QD** = Question Difficulty; ***** significant at $p < .05$.

Regarding medium preferences, 90.4% of all participants said they prefer to read on paper, compared to a 1.9% preference for reading on screen and 7.7% with no preference. Participants were also asked to predict how difficult it will be to learn from either print text, scrolling text, or hypertext (when completing the PIEpre, they were unaware of which reading condition they were in). Overall, participants predicted hypertext would be the most difficult to learn from ($M = 4.19$, $SD = 1.29$), followed by scrolling text ($M = 3.56$, $SD = 1.06$) and print text ($M = 2.12$, $SD = 1.28$).

While there was no significant main effect of text condition on pre-test (p = .504), or post-test (p = .126) comprehension test score predictions, there was a significant main effect of prior knowledge on both pre-test (p = .011) and post-test (p = .002) predictions, with high prior knowledge participants reporting significantly greater pre-test and post-test comprehension score predictions than those with low prior knowledge. There were no interaction effects between prior knowledge and reading condition for pre-test (p = .760) and post-test (p = .757) predictions.

6.6.6 Reading Strategies

This section will explore the most and least-preferred strategies across all groups. A two-way between subjects MANOVA was conducted to assess whether there were any differences in responses between groups (for the three text conditions, or two prior knowledge conditions), for items 1-12 of the reading strategies questionnaire (scored as previously described). It found that there was a significant main effect of text condition on responses to item eight ('I found it easy to distinguish between the beginning, middle, and end of the text'), p = .012. Those reading print text reported that they found it easier to distinguish between the beginning, middle and end of the text than those reading hypertext. It also found that there was a significant main effect of prior knowledge on responses to items seven ('I became lost/confused when navigating through the text', p = .035; eight, p = .001; and 11 ('I felt time pressure while I was reading the text'), p < .001. Low prior knowledge participants said that they became more lost/confused while navigating the through text and felt the time pressure while they were reading the text more than high prior knowledge participants. Alternatively, high prior knowledge participants reported that they found it easier to distinguish between the beginning, middle and

end of the text than those with low prior knowledge. There was no interaction effect of prior knowledge and reading condition on any of these items.

The most preferred strategies were to 'revisit pages which contained information I found difficult to remember" (M = 4.63, SD = 1.52), and to 'try to find connections between different parts of the text' (M = 4.10, SD = 1.26). The least preferred strategies were to take the time to 'become familiar with the website's layout before I read the information' (M = 2.33, SD = 1.29), and to 'use the pictures to help me navigate through the text' (M = 2.12, SD = 1.46). Of the remaining reading strategy items which had multiple response options, the most popular reported strategy of hypertext readers when first opening the webpage, was to start reading immediately (78.3%).

Hypertext readers said that they engaged with hyperlinks by clicking them after they had finished reading the page (52.9%), and on pages which contained more than one hyperlink, opted to click the one which appeared first (76.5%). Readers across all conditions reported sections with pictures on were easier to locate again (31.0%), that they re-read sections they did not fully understand once they were sure they had read all of the sections (48.5%), and used the reading time to spend longer on pages where the information was more difficult to learn (44.7%). Table 6.14 shows the mean scores for items 1-12, and Table 6.15 shows the percentage of participants who selected each of the options for items 13-20.

Table 6.14

Overall scores for items 1-12 of reading strategies questionnaire.

Question Number	Description	*M*	*SD*	*p*	
				Reading Condition	Prior Knowledge
4	'Difficult information'	4.63	1.52	.870	.951
1	'Connections'	4.10	1.26	.556	.728
3	'Stopped to read'	4.04	1.33	.247	.905
6	'Aim of task in mind'	3.75	1.37	.761	.497
7	'Became lost/confused'	3.58	1.61	.437	**.035***
5	'Easy to locate'	3.50	1.81	.603	.406
2	'Memorised separately'	3.42	1.60	.447	.848
8	'Beginning, middle, end'	3.37	1.80	**.012***	.001*
11	'Felt time pressure'	2.77	1.52	.888	**< .001***
10	'Was strategic in time'	2.37	1.46	.174	.601
9	'Became familiar'	2.33	1.29	.574	.488
12	'Used pictures'	2.12	1.46	.505	.051

***** significant at $p < .05$.

Table 6.15

Proportion of participants who selected each of the options for items 13-20 of reading strategies questionnaire (%).

Question Number	Statement	Options	%
13*	'First opened…'	Read immediately	78.3
		Relevant	16.7
		Became familiar	5.0
14	'New section'	Read immediately	77.8
		Relevant	22.2
15*	New hyperlink	Relevant to goal	23.5
		Clicked immediately	17.6
		Clicked after reading	52.9
		Clicked after sentence	5.9
16*	1+ hyperlink	Clicked first one	76.5
		Clicked last one	23.5
17*	After clicking hyperlink	Continued though	38.9
		Went back	61.1
18	Picture	More relevant	14.3
		More interesting	20.2
		Easier to learn	28.6
		Easier to locate	31.0
		Spent longer on page	6.0
19	After reading	Stopped reading	11.8
		Re-read sections	48.5
		Skim-read through	39.7
20	Use of time	Equal time on pages	7.9
		Difficult pages	44.7
		Left time to revisit	25.0
		Quickly as possible	6.6
		Did not think	15.8

Note. ***** question answerable by those in the hypertext condition only.

6.6.7 Navigation Behaviour

Analyses were conducted to assess whether there was an effect of prior knowledge on navigation (time spent per page, clicking behaviour). It was predicted that more strategic and knowledge-seeking navigational behaviours would be positively related to comprehension.

Average Time Spent Per Page

A one-way between subjects ANOVA was conducted to assess whether there was an effect of prior knowledge on overall average time spent per page (scored as previously described; Table 6.16). Pages participants did not visit were excluded from the calculations. There was no significant main effect of prior knowledge on average seconds per page, $F(1, 14) = .183$, $p = .676$, partial $\eta^2 = .013$. Both low and high prior knowledge participants spent a similar overall average number of seconds per page when reading from hypertext.

Table 6.16

Average time (seconds) per page for high and low prior knowledge hypertext readers.

Prior Knowledge	*N*	Average Time Spent Per Page	
		M	*SD*
Low	12	116.58	20.81
High	4	111.50	19.77
Overall	16	115.31	20.03

A one-way between subjects MANOVA was conducted to assess whether there was an effect of prior knowledge on average time spent per page separately. Pages participants did not visit were excluded from the calculations. With the exception of one page (5.0), the two groups did not differ in the average amount of time spent on the pages. These results are shown in Table 6.17.

Table 6.17

Average time (seconds) per page.

Page Number	Prior Knowledge	Average Time Spent Per Page		*p*
		M	*SD*	
1.0	Low	231.25	67.10	.099
	High	169.25	27.57	
1.1	Low	130.92	44.13	.663
	High	118.25	64.90	
2.0	Low	114.17	62.62	.303
	High	158.75	99.91	
2.1	Low	58.58	66.24	.588
	High	79.50	62.19	
2.2	Low	34.83	38.47	.113
	High	1.50	3.00	
3.0	Low	103.58	62.50	.076
	High	39.25	37.52	
3.1	Low	63.42	56.80	.667
	High	76.75	32.17	
3.2	Low	55.92	46.67	.535
	High	72.00	30.42	
4.0	Low	71.17	42.31	.808
	High	77.00	34.14	
5.0	Low	136.33	80.42	**.024***
	High	244.00	40.16	

Page Number	Prior Knowledge	Average Time Spent Per Page		*p*
		M	*SD*	
6.0	Low	92.92	75.62	.561
	High	69.50	25.84	
6.1	Low	83.00	60.23	.875
	High	88.00	18.60	

* significant at $p < .05$.

'Clicking' Behaviour

The number of 'clicks' participants made during the reading task was captured. The log-files recorded each time hypertext readers clicked on either an embedded hyperlink or the 'back to previous page' button. When one of these interactions occurred, one click was recorded. An independent samples t-test assessed whether low prior knowledge or high prior knowledge groups differed on the number of clicks made during the reading task, finding no significant difference between groups, $t(14) = -.290$, $p = .776$. Table 6.18 shows the average number of clicks made by both low and high prior knowledge readers and overall during the reading task.

Table 6.18

Average number of clicks made by both low and high prior knowledge hypertext readers.

Prior Knowledge	*N*	Average Number of Clicks	
		M	*SD*
Low	12	37.33	24.62
High	4	41.25	18.23
Overall	16	38.31	22.67

Page Visits

The overall number of page visits was measured by summing the number of times each participant in the hypertext reading condition visited each one of the 12 pages of the text during the reading task (Table 6.19). A one-way between subjects MANOVA was conducted to assess whether there was an effect of prior knowledge on overall number of visits per page for those in the hypertext reading condition. While some pages were visited more than others, there was no significant main effect of prior knowledge on number of visits to any of the 12 pages of the text.

Table 6.19

Overall average number of visits per page.

Page Number	Average Number of Visits	
	M	*SD*
1.0	8.56	4.38
1.1	5.56	3.61
2.0	4.13	2.53
2.1	1.25	1.39
2.2	1.06	1.18
3.0	2.38	1.54
3.1	1.88	1.89
3.2	1.69	1.62
4.0	3.06	2.24
5.0	3.00	1.71
6.0	4.13	4.10
6.1	2.25	2.21

Navigation Styles

Hypertext readers' navigation behaviour was investigated. On average, participants spent 115 seconds per page, made 38 clicks, and scored 10 out of 20 on the reading comprehension test. Table 6.20 shows an overview of the strongest and weakest performers in each group including an interpretation of whether their navigation activities were beneficial for comprehension. The selected participants were representative of other participants with high and low comprehension scores in each group.

Table 6.20

Overview of strongest and weakest hypertext performers.

Performance	Score	PK	Clicks	Secs. Per Page	Navigation Summary	Interpretation
Highest	15	High	45	101	- Visited all pages with the first 10 minutes. - Several 'back' clicks to the previously read page so that they could click on a different hyperlink to the one they had initially clicked on pages with more than one. - Multiple page revisits ensured no pages were missed.	- Initial familiarisation period helped build representation of macrostructure, which facilitate navigation and was beneficial for comprehension. - Review period towards end of reading time benefited comprehension.
Lowest	6	High	39	101	- Only visited five pages in the first 10 minutes of the reading time. - Low number of page revisits. - Clicked on the same hyperlinks several times rather than new hyperlinks. - Spent final five minutes on one page rather than relocating information or locating new information. - No review period towards end of reading time.	- Poor time management and no initial familiarisation period detrimental to comprehension. - Favouring previously-clicked hyperlinks rather than new ones meant some information was missed.

6.6.8 Comparative Impact of Measures

Multiple regressions were calculated to predict overall comprehension of the three texts (print, scrolling, networked hypertext) based on the measures of prior knowledge (familiarity scores), working memory (verbal and visuospatial scores), reading strategies (total score on first 12 items of reading strategies questionnaire), and navigation (average time spent per page). Navigation was only entered into the model as a predictor for the networked hypertext condition (Table 6.21).

Print text. The model was not significant, and the four variables together accounted for 40% of the variation in overall comprehension performance, $F(4, 13) = 2.191$, $p = .127$, $R^2 = .403$. Only verbal working memory made a significant unique contribution ($p = .018$), meaning it was the best predictor of overall comprehension ($\beta = .581$).

Scrolling Text. The model was significant, and all four variables together accounted for 65% of the variation in overall comprehension, $F(4, 12) = 5.673$, $p = .008$, $R^2 = .654$. Only prior knowledge made a significant unique contribution ($p = .002$), meaning it was the best predictor of overall comprehension ($\beta = .506$).

Networked Hypertext. The model was not significant, and all five variables together accounted for 30% of the variation in overall comprehension, $F(5, 10) = .549$, $p = .538$, $R^2 = .301$.

Table 6.21

Results of multiple regressions.

Condition	Predictor	*B*	*SE B*	*β*	*t*	*p*
Print	PK	.180	.721	.056	.250	.806
	V WM	2.047	.760	.581	2.692	**.018***
	VS WM	.533	.812	.162	.656	.523
	Strategies	.237	.899	.066	.264	.796
Scrolling	PK	2.001	.506	.740	3.954	**.002***
	V WM	.191	.553	.078	.346	.735
	VS WM	.387	.631	.138	.613	.551
	Strategies	.546	.425	.220	1.284	.233
Hypertext	PK	.068	.571	.039	.120	.907
	V WM	.081	.606	.048	.133	.897
	VS WM	.653	.675	.389	.968	.356
	Strategies	.141	.576	.082	.245	.811
	Navigation	.367	.481	.245	.763	.463

*** s**ignificant at $p < .05$.

6.7 Discussion

The present study aimed to explore how students with high and low prior knowledge learn from and navigate hypertext. It investigated the differences between print and digital text learning by measuring the comprehension, working memory, and metacognitive experience of readers of print text, scrolling text, and networked hypertext. The navigation behaviours of hypertext readers were also explored. The main findings related to these measures will be discussed in this section. In addition, potential methodological limitations will be considered and directions for future research in this area will be recommended. Implications of these findings will be discussed in more detail in Chapter 8. Table 6.22 includes a brief summary of the main findings of this experiment.

Table 6.22

Results summary.

Variable	Key Findings
Familiarity	- High prior knowledge group had highest familiarity scores.
Reading Comprehension	- Those in the print and scrolling text reading conditions performed best on overall and integration comprehension. - High prior knowledge hypertext (but not print or scrolling text) readers scored higher on overall and integration comprehension than those with low prior knowledge.
Confidence Ratings	- Underconfidence in print and scrolling text readers with low prior knowledge. - Overconfidence in hypertext readers with high prior knowledge.
Working Memory	- Positive relationship between verbal working memory and overall and textual comprehension. - No relationships between visuospatial working memory and comprehension.
Predictions, Interest, Engagement	- Overall preference for learning from print versus digital texts - Hypertext predicted to be most difficult medium to learn from. - Overconfidence before reading task, and underconfidence afterwards.
Reading Strategies	- Those in the print text and high prior knowledge groups found it easiest to distinguish between the beginning, middle, and end of the text. - Those in the hypertext and low prior knowledge groups became the most lost/confused while navigating, and felt greater tie pressure.
Navigation	- Most beneficial = visit pages more than once, spend longer on pages. - Least beneficial = no familiarisation period, short interactions with pages.

6.7.1 Reading Comprehension

The main aim of the present experiment was to explore learning across study media. It was predicted that print text readers would achieve higher comprehension than those reading from scrolling text and hypertext (**H_1**). The study found that readers of both print text and scrolling text had higher comprehension than hypertext readers, with those in the print text condition scoring the highest. This supports others' claims that there is an overall advantage for learning from print text over hypertext, possibly due to hypertext structure being more unfamiliar and difficult to navigate, resulting in time spent constructing a mental representation of an organisational structure rather than inferencing and relating new information to readers' prior knowledge (e.g., Ackerman & Goldsmith, 2011; Ackerman & Lauterman, 2012; Delgado et al., 2018; Salmeron et al., 2005, 2016, 2018).

The hypothesis **H_3** predicted that hypertext readers would score lower on integration comprehension than print and scrolling text readers. The present study found that hypertext demonstrated weaker integration comprehension compared to print and scrolling text readers. Processing hypertext requires readers to fill in information gaps (e.g., with prior knowledge) and to self-regulate their learning (e.g., when selecting links or remembering their pathways). In addition, learning from hypertext requires integration of information from different locations, the formation of semantic relationships between information parts, and the maintenance of coherent reading pathways by clicking relevant hyperlinks (Madrid et al., 2009; Salmerón et al., 2005). All these necessary processes may be challenging for learners, especially for those with low prior knowledge as they are less able to fill in information gaps, resulting in weaker comprehension.

6.7.2 Role of Prior Knowledge

This study investigated the effect of prior domain knowledge on learning across study media. The C-I model considers many factors to be contributory to text comprehension but assumes that prior knowledge, inferencing, and coherence are among the most important (Kintsch, 1988; Kintsch & van Dijk, 1978; Rouet & Le Bigot, 2007). Integrating prior knowledge with new information within a text is important for deeper comprehension as it enables the reader to make inferences beyond what is explicitly mentioned. However, if features of a text make it difficult to form coherent mental representations (e.g., of syntactic or chronological structure), then readers' ability to integrate prior knowledge is impaired and comprehension suffers.

As expected, those with high prior knowledge performed better on all three measures of comprehension (overall, textual, integration) than those with low prior knowledge (supporting $\mathbf{H_2}$). When looking at the effect of prior knowledge on the comprehension of each text separately, both low and high prior knowledge participants performed similarly when learning from print and scrolling texts. However, differences emerged for those learning from hypertext; low prior knowledge readers scored lower on integration comprehension scores than those with high knowledge. Furthermore, low prior knowledge hypertext readers had the lowest comprehension scores of all groups.

Previous research has suggested that readers with low knowledge may find it difficult to apply learned strategies to reading hypertext and fill in coherence gaps with previously learned knowledge because cognitive resources are instead used for building text structure and processing hyperlinks (Amadieu et al., 2009; DeStefano

& LeFevre, 2007; Naumann et al., 2008; Salmerón & García, 2011). In contrast, high prior knowledge readers of hypertext may benefit from these coherence gaps. For example, a review of research exploring deep learning from multimedia and hypertexts suggested that digital documents can support deep comprehension by requiring relational processes between relevant information parts (Amadieu et al., 2017). The authors suggested that coherence gaps imposed by hypertexts trigger deep inferential activity in learners with a high level of domain background knowledge, resulting in deeper comprehension.

Therefore, this may explain why there were differences in inferential comprehension between prior knowledge groups for those reading hypertext and not the other two text conditions; hypertext impacts low prior knowledge readers' ability to engage in inferential activity, whereas it facilitates deep comprehension in high knowledge readers. In relation to navigation, both low and high prior knowledge participants made a similar number of clicks, a similar number of visits to each individual page of the text and spent a similar average amount of time on each page. Future research should explore ways to facilitate inferential processes in low knowledge hypertext readers.

A potential limitation of the prior knowledge findings in this study is the weak generalisability due to the low numbers of participants in the high prior knowledge group compared to the low prior knowledge group. Small subgroups can result in less variability in the scores relative to the mean, negatively impacting the ability to make assumptions about the effects of prior knowledge on comprehension. There were additional challenges to recruiting high prior knowledge participants, as they had to have high levels of experience in the topics of the text to satisfy their

placement in this group. Third-year undergraduates and PhD students were selected because it was assumed that they would have had at least some experience in learning about working memory topics as part of their courses. However, there may have been variability of the knowledge base within this group due to different learning experiences across institutions and the length of time since they had been exposed to working memory information.

Inclusion of a familiarity questionnaire ensured that participants were appropriately grouped as either high or low prior knowledge, but the requirement for them to be sufficiently knowledgeable in the few specific topics of Psychology limited the number of eligible students for recruitment. In addition, there may have been greater pressure on the high prior knowledge group to say that had more experience with the working memory concepts on the familiarity questionnaire than low prior knowledge participants due to demand characteristics. To mitigate this risk, participants were not explicitly told that they were in either the high or low prior knowledge groups until the end of the study. A future study may assess fewer groups, use a broader text topic, or recruit from multiple institutions to improve group comparisons and the generalisability of findings to high prior knowledge students in other domains.

Moreover, differences in how high and low prior knowledge participants were incentivised to take part in the experiment may have affected motivation across groups. The high prior knowledge group received £5 for participating, whereas the low prior knowledge group received research participation credits. While the monetary and research credit value was consistent with other one-hour research projects in the university, participants who received money may have been more

motivated to perform well than those who received research credits. A future study may ask participants to report their motivation to perform well on the reading tasks, and to report whether the participation incentive impacted their motivation, to assess the equivalence of incentivisation methods between groups.

6.7.3 Role of Working Memory

As previously mentioned, when working memory capacity is low, cognitive resources required for processing new textual information can quickly become overburdened, inhibiting performance and the ability to connect ideas (Nouwens et al., 2017). Therefore, readers with low working memory ability may be particularly disadvantaged when answering more inferential-based comprehension questions, and instead rely on prior knowledge. Moreover, when prior knowledge is also low, this may impact comprehension twofold. In support of this, hypertext readers with the lowest comprehension scores were in the low prior knowledge group and had low verbal and visuospatial working memory scores.

Interestingly, a significant positive correlation was found between verbal working memory and comprehension scores, but not between visuospatial working memory and comprehension. It has already been suggested that the non-linearity of hypertext structure may be responsible for weaker comprehension scores than in print text, with the results of previous experiments in this thesis supporting this claim. Therefore, it was expected that visuospatial working memory ability would be positive related to comprehension, as greater ability has been associated with identifying structure and locating and connecting ideas in hypertext (Burin et al., 2015). An explanation for this may be that networked hypertext greatly disrupts the construction of coherent mental representations, so that higher visuospatial working

memory ability alone is not enough to overcome the negative impact on comprehension. Alternatively, Pazzaglia et al. (2008) suggested that while visuospatial working memory has a role in students' ability to construct a mental representation of text structure, verbal working memory is a greater predictor of the semantic knowledge they derive from hypermedia learning.

6.7.4 Metacognitive Experience

While the present study found that hypertext readers had the weakest comprehension scores, there was no effect of study media on score predictions or confidence ratings. However, there was some support for an underconfidence effect in readers of print and scrolling text, compared to overconfidence in hypertext readers. Moreover, high prior knowledge participants generally reported higher confidence in their answers than those in the low prior knowledge group. This suggests monitoring one's own learning may be more difficult when learning from hypertext than on paper. This may be because cognitive resources are allocated to building a representation of the organisational structure of hypertext, rather than to other effortful processes including evaluating how much information has been learned and integrating known knowledge with new information.

6.7.5 Individual Differences in Navigation Behaviour

In agreement with the findings of the previous experiments in this thesis (Chapters 4-5), the highest comprehension scores were achieved by readers who used a more methodical approach; they located all the pages early on to identify the organisation structure, and ensured they had clicked on each hyperlink on pages with more than one. They also managed their time more efficiently by reading all of the pages during the initial period, and then revisiting previously read pages containing

difficult information during the final five minutes. An initial familiarisation period may help readers construct an accurate mental representation or text structure, which allows them to navigate more efficiently (i.e., less time spent locating information, leaving more time for reading and learning). In contrast, the weakest comprehension scores came from readers who spent a disproportionate amount of time on the initial two or three pages they encountered, meaning that the remaining time consisted of many clicks and little time spent per page. Such navigation activity has already been shown to negatively impact comprehension because non-strategic readers often miss important information and do not use their time effectively (e.g., Blom et al., 2018; Lawless & Kulikowich, 2006).

Low prior knowledge readers also engaged in less strategic navigation behaviours, reporting that they became more lost/confused while navigating through hypertext and felt greater time pressure than those with high knowledge. This may have negatively impacted comprehension because they may have not been able to identify which information was the most difficult to learn, meaning they could not plan their reading time effectively. In contrast, high prior knowledge participants reported on the reading strategies questionnaire that they found it easier to distinguish between the beginning, middle and end of the text than those with low prior knowledge. This may be because they were able to integrate better what they already knew into the chronology of information, supporting the construction of a coherent situation model.

6.7.6 Implications and Directions for Future Research

The findings from this study contribute to the 'paper versus screen' debate. The results support the theory that the kind of deep processing involved in

integrating information and forming judgements about a text is impaired when learning through hypertext. The findings also suggest that hypertext impacts the comprehension of certain types of readers; those with low prior knowledge were particularly disadvantaged. In agreement with the findings of previous experiments presented in this thesis (see Chapters 4-5), the present study found no differences in comprehension scores for print text and scrolling text readers. This suggests that differences between study media were not the result of screen inferiority, rather they reflect the inherent challenges of learning from hypertext that are not as prevalent in linear text reading. These challenges include maintaining a coherent mental representation of the interrelational text structure, frequent disruption to working memory processes, and navigational disorientation.

Despite the findings of previous research highlighting the disadvantages of learning from hypertext, this format comprises a large part of the current digital reading corpus, and is used frequently by students for their academic work (Amadieu & Salmeron, 2007; Selwyn & Gorard, 2016). A survey of 1658 undergraduate students' use of digital technologies found that 87.5% reported using Wikipedia (the largest educational hypertext on the World Wide Web) for academic purposes, with 24% considering it 'very useful' for learning (Selwyn & Gorard, 2016). Therefore, it is unrealistic to suggest that students stop learning from hypertexts in favour of print texts; hypertexts are here to stay and can be useful tools for learning, even if they are used just for students to gain introductory or clarificatory information. Instead, future research should investigate ways to minimise the disadvantages of reading from hypertext and facilitate learning and navigation.

A limitation of this experiment is that some groups contained a small number of participants. This may affect the generalisability of the results to wider reading

contexts and other informational texts. However, this study was still able to reach some conclusions about the impact of prior knowledge on learning across study media that could be explained by relevant theory in this area. An alternative approach to investigating prior knowledge across study media would be to use a repeated measures design in which the same participants read both a low and high-prior knowledge text in the same format. For example, an expert in the topic of working memory could read two networked hypertexts about both working memory and a historical topic. This would allow for the exploration of how readers use reading strategies to facilitate the navigation and comprehension of high and low prior knowledge texts.

One of the most extensively researched tools for facilitating how hypertexts are processed are overviews (e.g., concept maps) that convey their spatial and/or semantic structure. A review of impact of concept maps on navigation and comprehension found that they are particularly beneficial for learners with low reading skills and low prior knowledge (Amadieu & Salmerón, 2014). Graphical overviews may improve comprehension of hypertexts by facilitating selection and organisation of contents (Naumann et al., 2007; Salmerón & García, 2011). Therefore, a future study should investigate whether the introduction of an overview facilitates the navigation and comprehension of hypertext in low and high prior knowledge readers.

Chapter 7: Experiment 4 – Overcoming Disadvantages of Hypertext: Does a Graphical Overview Facilitate Navigation and Comprehension?

This chapter describes the fourth in a series of empirical experiments on how students learn from and navigate through hypertext. The results of the previous three experiments described in this thesis (see Chapters 4-6) have shown several disadvantages of learning from hypertext. Firstly, the experiments indicated that reading comprehension may be weaker when learning from hypertext versus print text. Moreover, the more complex networked hypertext was found be particularly impactful on comprehension, with readers of this medium producing the weakest performance. Low prior knowledge participants were especially disadvantaged when learning from hypertext. Furthermore, users reported disorientation when navigating hypertext and used their reading time inefficiently. Difficulties in navigation were identified as an explanation for weaker learning outcomes. Consequently, it was suggested that further research should explore novel ways of improving the navigation and comprehension of hypertexts.

The primary focus of this study will be to explore the effect of a graphical overview on hypertext learning and navigation in low and high prior knowledge students. Some of the methodology used in this experiment is similar to that of previous experiments described in this thesis (see Chapters 4-6). In addition, relevant background information has also been previously described (see Chapters 1-3), so only new information related to the present experiment will be presented in this chapter.

7.1 Background

7.1.1 Facilitating Hypertext Learning and Navigation

Hypertexts are comprised of multiple individual pages which appear on screen only at the time of viewing; unlike in printed materials and other single linear texts, hypertexts are never fully visible to the user. Instead, users click on hyperlinks which present several paths between the pages, allowing for readers to construct their own navigational pathways. Padovani and Lansdale (2003) described hypertext navigation as involving moving from one point to another and learning the structure of the informational space. The order in which readers access information may be determined by a specific goal (e.g., finding an answer to a question), or browsing through several pages to locate related topics. Navigation via hyperlink selection is the activity by which readers construct mental representations of the semantic content and topological structure of a hypertext.

Multiple studies have found that hypertext readers create map-like a mental representation of structure during navigation (Britt et al., 1996; Dee-Lucas, 2012; Pazzaglia et al., 2008; Potelle & Rouet, 2003; Shapiro, 1998). However, complex hypertexts may inhibit the formation of coherent structural representations. This is because the topological structure of networked hypertexts is often confusing for readers, with numerous hyperlinks offering many navigation pathways which lead to potentially irrelevant or unrelated information. This may result in greater feelings of disorientation and an increase in cognitive load, which have been shown to negatively impact reading comprehension, especially for low skill learners (Amadieu & Salmerón, 2014; Antonenko & Niederhauser, 2010). Therefore, it is important to explore ways of reducing disorientation in hypertext by making the topological

hypertext structure less confusing for readers, which may facilitate navigation and improve comprehension.

Concept Maps and Graphical Overviews

One common method by which navigation of hypertext is facilitated is through the use of concept maps. Pre-structured concept maps reflect the topological structure of a hypertext, providing an explicit spatial overview of the contents' semantic organisation (Amadieu et al., 2015; Vörös et al., 2011). As such, they limit learners' disorientation by showing the reader which information is related, and where in the organisation of webpages it can be located. However, they do not promote deep and active elaboration processes based on prior knowledge; learners navigate more passively, following the structure imposed by the map rather than forming their own spatial organisation (Amadieu et al., 2009). Amadieu and Salmerón's (2014) review examined the effects of concept maps on students' hypertext navigation and comprehension. They concluded that maps support navigation by promoting the formation of a mental representation of structure. In addition, they found that concept maps are especially beneficial for learners with low reading skills and low prior knowledge as they do not contribute greatly to cognitive load. However, most of the concept maps they reviewed were static (i.e., their appearance did not change during the reading task), and some could only be accessed once before the reading task took place. The present study will explore the impact of a dynamic overview (i.e., appearance changes to represent where the reader is currently located in the text) which will be present throughout the reading task.

Concept mapping differs from pre-structured concept maps, in that it requires learners to structure a spatial overview of the semantic organisation of the text

themselves, rather than being provided with one. In doing so, they become active in global coherence formation processes including integrating multiple representations to gain a deep understanding of the contents (Karpicke & Blunt, 2011; Seufert, 2003). However, managing the two tasks of building a map and reading the information itself can be challenging, and previous research has suggested that concept mapping may not be particularly efficient for learning (Redford et al., 2012). Another navigation aid is leads, which are types of 'advance organiser' designed to help orient and prepare the reader for information in a separate node. In hypertexts, leads show the reader information contained in a hyperlinked page while the current page is still visible. One way in which this is done is by the user hovering their mouse over a hyperlink which causes a balloon to pop up next to the hyperlink previewing the hyperlinked information. Leads have been found to decrease extraneous cognitive load and promote germane load thereby improving learning (Antonenko & Niederhauser, 2010).

An alternative to concept maps and leads is the graphical overview, which, instead of showing related concepts and inferred semantic connections between pages (as with concept maps), focuses more on providing an explicit graphical representation of the hypertext structure and navigation pathways. According to Mayer's (1979) Assimilation Theory, graphical overviews presented prior to reading provide an organisational framework which may enable readers to construct accurate mental representations (such as a situation model representation) and increase memory of text structure. In addition, cognitive flexibility theory suggests that an explicit representation of hypertext structure may support the reader in the flexible construction of the situation model. Therefore, the present study will make use of a graphical overview to facilitate navigation, because there is evidence that challenges

related to identifying structure and navigating pathways are the primary factors negatively impacting hypertext readers' comprehension.

A potential limitation of graphical overviews is proposed by the Active Processing model, which suggests that highly structured overviews may inhibit readers' comprehension strategies by limiting the need for discovering relations between sections, something which has been related to weaker comprehension (Hofman & van Oostendorp, 1999; Shapiro, 1998). According to this model, when an overview is read at the beginning of the hypertext, it acts as a schema for text organisation, allowing for the incorporation of information into an existing representation. However, in this situation, readers do not need to discover the macrostructure of the hypertext for themselves, which may result in lower text comprehension. Similarly, if a student is presented with an overview at the end of the hypertext, it may inhibit the active processing of information because readers may reorganise their representation at the time of processing the overview. This contrasts the Assimilation Theory, which suggests a student reading an unfamiliar or difficult text may be overloaded by the task of constructing a representation for the hypertext organisation, which may result in a representation including irrelevant or unorganised information (Lorch & Lorch, 1996; Mayer & Bromage, 1980). However, the theory follows that reading an overview at the end of the reading task will not have a detrimental effect on comprehension because overviews only influence the encoding of new information (Mayer, 1979).

Salmerón et al. (2009) investigated how graphical overviews presented at either the beginning or end of an expository hypertext impacted comprehension in low and high prior knowledge undergraduate students, and interpreted the findings in relation to the Assimilation Theory and the Active Processing model. As expected,

Salmerón et al.'s (2009) study found that reading an overview at the beginning of the hypertext was related to increased comprehension of more difficult texts, whereas reading an overview at the end of the hypertext was related to decreased comprehension of easier texts. They concluded that each of the theories is well suited to different learning situations; the Assimilation Theory explains situations where it is more difficult for students to learn from hypertexts (e.g., due to complex hypertext structure or low prior knowledge), whereas the Active Processing Model explains easier hypertext reading situations (e.g., highly structured hypertext or high prior knowledge). In the present study, the graphical overview will always be present during the reading task. In addition, the networked hypertext has an inherently complex structure, making the reading situation more difficult. The study will explore the navigation and comprehension of both low and high prior knowledge readers, and will explore whether the results can be accounted for by either of these theories.

7.1.2 Individual Differences

Working Memory

According to the cognitive load theory, a deeper level of hypertext comprehension is dependent on prior knowledge and working memory ability (Sweller, 1988). Previous research has found that ineffective information presentation in hypertext may lead to an increase in extraneous cognitive load, and negative learning outcomes (Kester & Kirschner, 2009; Sweller et al., 1998). Moreover, a recent study analysed the brain activity of university students while reading hypertext and found additional cognitive load when they decided whether to click on a hyperlink (Scharinger et al., 2015). A challenge for research exploring

ways of facilitating navigation of hypertexts is to ensure any additional cognitive load of processing overviews and other visual aids does not negatively impact performance. For example, the presence of a highlighting tool has been found to increase cognitive load and impact comprehension of a networked hypertext, especially for low prior knowledge learners (Li et al., 2016). Conversely, leads have been found to decrease extraneous cognitive load, and improve germane cognitive load, which contributed to improved comprehension and the formation of a situation model (Antonenko & Niederhauser, 2010). Similarly, Amadieu and colleagues (2009) found that textual comprehension in readers with low prior knowledge was not affected by the presence of a graphical overview.

Previous research has found a positive relationship between visuospatial working memory and hypertext navigation and comprehension (Lee & Tedder, 2003; Lee & Tedder, 2004; Pazzaglia et al., 2008; Vörös et al., 2009). For instance, Amadieu and Salmerón (2014) found that a graphical overview is helpful for readers with low visuospatial working memory, but less helpful for those with high visuospatial working memory. The researchers suggested that future research explore whether the usefulness of a graphical overview is also affected by readers' verbal working memory. The present study predicts a positive effect of graphical overview on comprehension, and that higher visuospatial working memory readers with a graphical overview will have the best comprehension scores.

Prior Knowledge

One factor which may be influential in how beneficial graphical overviews are for navigation and comprehension of hypertext is prior knowledge. Previous research has found that learning outcomes were higher for students reading linear

text than networked hypertext, but only for readers of low prior knowledge and low working memory ability (Amadieu et al., 2010; Lee & Tedder, 2004; Potelle & Rouet, 2003). Salmerón and colleagues' (2005) literature review found that readers with high prior knowledge generally did not benefit from an overview, whereas the results were mixed in readers with low prior knowledge. A more recent study found that while there was no difference in comprehension of a hypertext, a graphical overview was beneficial in sixth graders with low prior knowledge (Fesel et al., 2017). Another recent study found no influence of prior knowledge on the relationship between text design (networked hypertext versus linear digital text) and comprehension in students reading with or without a graphical overview (Blom et al., 2018). However, the comprehension measure used within this study was text-based, and did not require a deeper level of understanding. The present study will explore the effect of a graphical overview on different levels of comprehension (textual versus inferential) in low and high prior knowledge participants.

7.2 Aims and Hypotheses

An experiment was conducted with the aim of investigating how students learn from and navigate through hypertext. It explored the effect of a graphical overview on the comprehension performance of both low and high prior knowledge learners and assessed the relationship between working memory, metacognitive experience, navigation behaviour, and comprehension. It sought to address the following hypotheses:

H_1: Readers with a graphical overview will score higher on comprehension than those without.

H_2: There will be a significant interaction effect of prior knowledge and graphical overview, with low prior knowledge readers without a graphical overview having the weakest comprehension scores of all groups.

H_3: There will be a strong positive correlation between working memory ability and comprehension scores for readers with a graphical overview.

H_4: Readers with an overview will report fewer navigational difficulties (e.g., disorientation) than those without.

7.3 Method

Measures retained in this study from experiments described in earlier chapters include an informational text about working memory (from Chapter 6), reading comprehension test, PIEpre and PIEpost questionnaires, verbal and visuospatial working memory tests, reading strategies questionnaire (from Chapter 6), and metacognitive items (see Chapters 4-6).

7.3.1 Design

The study made use of a between-subjects experimental design in which 52 participants were assigned to either one of the following two networked hypertext reading conditions: with graphical overview (N = 26), or without graphical overview (N = 26). Participants were designated as either low prior knowledge (N = 31), or high prior knowledge (N = 21). This resulted in participants being placed into one of four conditions (see Figure 7.1 for overview of reading conditions). The networked hypertext in this experiment was the same as the one used in Chapter 6. Participants were randomly assigned, and blinded to, their reading conditions.

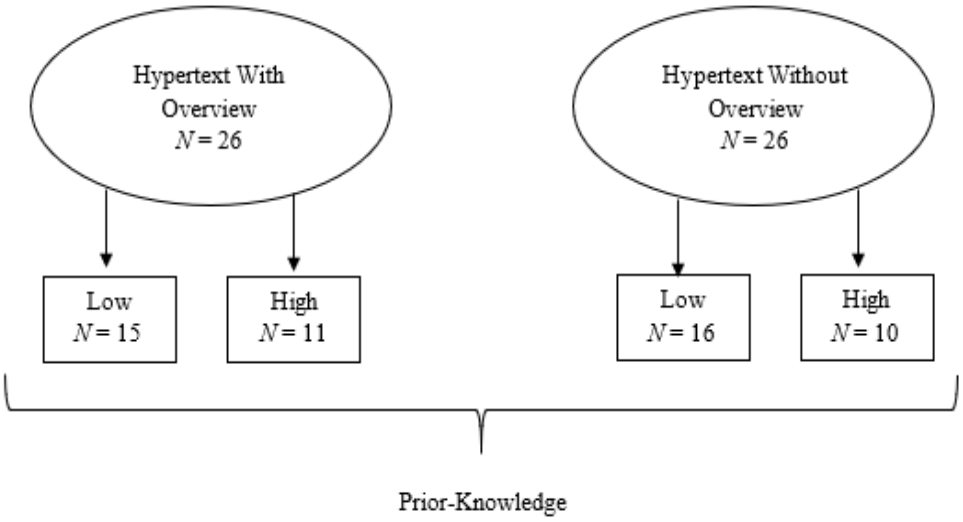


Figure 7.1. Overview of conditions.

Graphical Overview. Participants who were in the *with graphical overview* reading condition had an image of the hypertext layout on the left-hand side of the screen, beside the text (Figure 7.2). This overview consisted of 12 white squares representing the 12 individual webpages of the text. Each square contained text of the title of each page, e.g., 'The Phonological Loop', and highlighted in yellow when the reader was currently on that page. The overview was dynamic in that each time the reader clicked on a hyperlink to navigate to another page, the overview would change so that the page the reader was currently on became highlighted. The 'pages' were connected by a series of arrows representing where the reader could navigate to/from at each section. Arrows which went from the current page were highlighted in bold red colour, to clearly distinguish them from the other arrows on the overview. From this, readers could see how each page of the text was related to others, and how many navigation decisions each page contained.

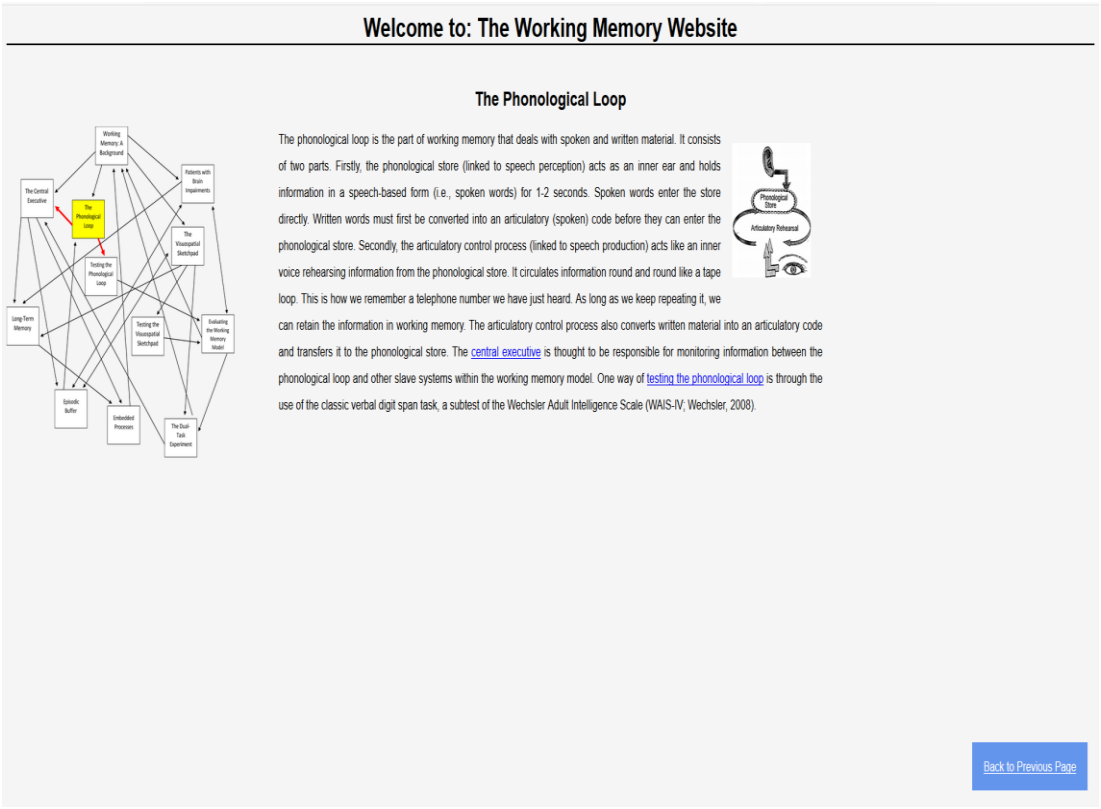


Figure 7.2. Readers' view of one page of the text in the graphical overview reading condition (graphical overview on left-hand side of image).

7.3.2 Participants

The study consisted of a sample of 52 healthy participants, recruited from the university campus via an online study recruitment program. There were 14 males (26.9%) and 38 females (73.1%), ranging from 18 to 34 years of age (M = 22.17, SD = 5.11). Individuals who responded to the experimenters were allocated a timeslot to participate. Low prior knowledge participants were first-year undergraduate students in psychology, high prior knowledge participants were either third-year psychology undergraduates, psychology postgraduates, or psychology PhD students with experience of studying the topic of working memory and related concepts. Low prior knowledge participants who successfully completed the study received 60

participation credits; high prior knowledge participants received five pounds for taking part. Participants were not subject to any exclusion criteria.

7.4 Measures and Materials

7.4.1 The Text

Each participant read the same informational text regardless of which of the two prior knowledge or reading conditions they were in. The informational text used in this experiment was the same one as used in experiment 3 (see Chapter 6).

7.4.2 Graphical Overview Usage

Following the reading task, those who were in the *with graphical overview* condition received a 12-item graphical overview usage questionnaire in which participants responded on a six-point scale to statement items related to the extent to which they made use of the overview. Since this experiment was the first to incorporate a graphical overview, this questionnaire was new.

7.5 Procedure

The procedure used in this experiment was the same as the one used for experiment 3 (Chapter 6), except for the following changes:

Participants were randomly assigned to one of two reading conditions: hypertext with graphical overview, or hypertext without graphical overview. Those in the with graphical overview condition were briefly shown what the graphical overview would look like before taking part in the reading task.

7.6 Results

This section will report the results of the present experiment. It will begin with the familiarity questionnaire, as this measure was important in determining whether low and high prior knowledge participants were appropriately grouped (i.e., according to the amount of knowledge they had about working memory and related concepts). The section will then report the results of the reading comprehension, working memory, confidence ratings, PIE, reading strategies, graphical overview usage, and navigation measures. Finally, integrative analysis will be reported, assessing the comparative impact of each of the measures on reading comprehension.

7.6.1 Familiarity

As expected, high prior knowledge participants (M = 36.81, SD = 6.07) had significantly greater overall familiarity scores than the low prior knowledge group (M = 21.26, SD = 5.74), $F(1, 52) = 87.24$, $p < .001$, partial $\eta^2 = .645$. Low prior knowledge participants were most familiar with the theoretical background to working memory (M = 3.06, SD = .81), and least familiar with The Embedded Processes Model (M = 2.12, SD = 1.15). High prior knowledge participants were most familiar with The Phonological Loop (M = 5.14, SD = 1.15), and least familiar with The Embedded Processes Model (M = 3.67, SD = 1.43. Participants generally spent at least four to six hours reading online for leisure versus one to three hours reading print text for leisure, and between one to three hours reading print text and online for university work. They also reported that they spent one to three hours per week reading from hypertext. Table 7.3 shows the descriptive statistics for all nine items of the familiarity questionnaire across each condition.

Table 7.3

Average ratings for familiarity questionnaire items across each condition.

Question	Description	Condition			
		Overview		No Overview	
		Low	High	Low	High
1	WM	3.00	4.55	2.94	4.90
2	Background	3.07	4.82	3.06	4.82
3	CE	2.87	4.64	2.94	5.20
4	PL	2.80	4.64	2.94	5.70
5	VSS	2.27	5.00	2.31	4.90
6	Episodic B.	2.27	4.27	2.44	4.00
7	Emb. Pro.	2.07	3.36	2.19	4.00
8	LTM	2.60	4.18	2.75	4.30
9	Print	2.13	1.64	1.81	2.40
	Online	3.33	3.64	3.25	3.90
	Uni Online	2.20	4.18	2.81	2.90
	Uni Print	2.27	2.36	2.44	2.30
	Hypertext	2.07	3.00	2.31	3.20

7.6.2 Reading Comprehension

All 20 reading comprehension items were scored as either correct (1) or incorrect (0) for a maximum overall score of 20, a maximum recall textual score of 10, and a maximum integration score of 10. Overall, test scores ranged from 7 to 18 with a mean score of 12.81. Overall, there was a mean score of 7.29 on textual

items, and a mean score of 5.62 on integration items. There was 64.0% overall comprehension accuracy, 69.2% accuracy in the with graphical overview reading condition, and 58.8% accuracy in the without graphical overview reading condition. Therefore, participants performed best when they read hypertext with a graphical overview versus without. These results are displayed in Table 7.4. Reliability analyses of the reading comprehension test questions showed a sufficient Cronbach's alpha for both the textual (α = .65) and integration (α = .79) items.

Overall Scores. The hypothesis **H_1** predicted that those with a graphical overview would achieve higher comprehension scores than those without. A two-way between subjects ANOVA was conducted to assess the effect of reading condition and prior knowledge on overall comprehension test scores out of 20. In support of **H_1**, there was a significant main effect of reading condition on total test scores, $F(1, 48) = 7.54$, $p = .008$, partial $\eta^2 = .136$. Participants with a graphical overview performed significantly better than those without a graphical overview ($p = .008$). There was also a significant main effect of prior knowledge on total comprehension test scores, $F(1, 48) = 26.02$, $p < .001$, partial $\eta^2 = .352$, with high prior knowledge participants ($M = 15.10$, $SD = 2.70$) performing significantly better on overall comprehension than those in the low prior knowledge group ($M = 11.25$, $SD = 2.77$). There was no interaction effect of reading condition and prior knowledge ($p = .541$). High prior knowledge readers ($M = 15.10$, $SD = 2.70$) performed better than low prior knowledge readers ($M = 11.26$, $SD = 2.77$), regardless of whether or not they had a graphical overview. In support of **H_2**, low prior knowledge readers without a graphical overview had significantly weaker comprehension scores compared to other gtoups.

When reading with a graphical overview, high prior knowledge participants (M = 16.27, SD = 2.89) performed significantly better than those with low prior knowledge. When reading without a graphical overview, high prior knowledge participants performed significantly better than those with low prior knowledge.

Textual Scores. A two-way between subjects ANOVA was conducted to assess the effect of reading condition and prior knowledge on correct responses for the 10 textual items in the comprehension test. There was no significant main effect of reading condition on textual item scores, $F(1, 48) = .58$, $p = .450$, partial $\eta^2 = .012$, meaning those with a graphical overview performed similarly to those without an overview. There was a significant main effect of prior knowledge on textual item scores, $F(1, 48) = 18.12$, $p < .001$, partial $\eta^2 = .274$, meaning high prior knowledge participants performed significantly better on textual comprehension items than those in the low prior knowledge group. There was no interaction effect of overview condition and prior knowledge ($p = .886$). High prior knowledge readers (M = 8.48, SD = 1.44) performed better than low prior knowledge (M = 6.48, SD = 1.77) readers performed better than low prior knowledge readers, regardless of whether or not they had a graphical overview.

Integration Scores. A two-way between subjects ANOVA was conducted to assess the effect of reading condition and prior knowledge on correct responses for the 10 integration items in the comprehension test out of 10. Participants with a graphical overview had significantly higher integration scores than those without, $F(1, 48) = 29.21$, $p < .001$, partial $\eta^2 = .378$. High prior knowledge participants had significantly higher integration scores than those with low prior knowledge, $F(1, 48) = 28.29$, $p < .001$, partial $\eta^2 = .371$. There was no interaction effect of text condition and prior knowledge ($p = .630$). High prior knowledge participants performed

significantly better than those with low prior knowledge both with ($p < .001$) and without (p .006) an overview.

Table 7.4

Mean overall, textual, and integration comprehension scores across each condition.

Comprehension	PK	Overall		Graphical Overview			
				No Overview		Overview	
		M	*SD*	*M*	*SD*	*M*	*SD*
Overall	Low	11.26	2.77	10.50	2.50	12.07	2.89
	High	15.10	2.70	13.80	2.70	16.27	2.20
Textual	Low	6.48	1.77	6.23	1.75	6.33	1.84
	High	8.48	1.44	8.70	.95	8.27	1.79
Integration	Low	4.74	1.67	3.81	1.33	5.73	1.44
	High	6.90	1.79	5.70	1.89	8.00	.63
Range (min. – max. scores)		11 (7-18)		10 (7-17)		11 (7-18)	

7.6.3 Working Memory

Analyses were conducted to test the relationships between working memory and comprehension across study media and prior knowledge groups. Since there was a significant positive correlation between verbal span and raw scores, $r(50) = .947$, $p < .001$, and visuospatial span and raw scores, $r(51) = .938$, $p < .001$, only verbal and visuospatial raw scores will be reported.

Verbal Working Memory

Performance on the verbal working memory test (scored as previously described) was best for forwards order (M = 8.04, SD = 1.33) and weakest for reverse order (M = 5.38, SD = 1.36). There were no significant differences in verbal working memory scores between graphical overview groups, $F(3, 50) = .92$, $p = .343$, partial $\eta^2 = .019$. There were also no differences in scores between prior knowledge groups. Therefore, each group included participants of similar verbal working memory ability (Table 7.5).

Table 7.5

Descriptive statistics for each trial of verbal working memory test across all groups.

Trial	PK	Graphical Overview			
		No Overview		Overview	
		M	*SD*	*M*	*SD*
Overall	Low	13.44	2.16	13.87	1.68
	High	14.50	2.46	15.18	1.94
Forward	Low	8.00	1.41	7.73	1.16
	High	8.00	1.25	8.55	1.51
Reverse	Low	5.06	1.29	5.07	1.10
	High	5.80	1.81	5.91	1.22
Sequencing	Low	5.69	1.14	5.80	1.37
	High	6.00	.67	6.55	1.21

Pearson's correlations which assessed the relationship between participants' verbal working memory scores (max. = 48), and overall (max. = 20), textual (max. = 10), and integration (max. = 10) comprehension scores across both graphical

overview conditions, found no significant relationships between verbal working memory and overall (p = .061), textual (p = .221), and integration (p = .086) comprehension. Additional correlations assessed the relationship between verbal working memory and comprehension for each group separately, finding that the verbal working memory of those in the overview condition was positively correlated with overall, textual, and integration comprehension (Table 7.6).

Table 7.6

Correlations between verbal working memory and comprehension for each condition.

Condition/Comprehension	Overall		Textual		Integration	
	r	*p*	*r*	*p*	*r*	*p*
No Overview	.841	**.041***	-.079	.700	.100	.628
Overview	.463	**.017***	.435	**.026***	.406	**.040***

***** significant to $p < .05$.

Visuospatial Working Memory

Performance on the visuospatial working memory test (scored as previously described) was best for forwards order (M = 7.34, SD = 1.55), and weakest for reverse order (M = 6.75, SD = 1.72). There was no significant difference in visuospatial scores between text condition groups, $F(1, 48) = .38$, p = .538, partial η^2 = .008. The same was found for the prior knowledge groups. Therefore, each group included participants of similar visuospatial working memory ability. The descriptive statistics for both trials of the visuospatial working memory test are shown in Table 7.7.

Table 7.7

Descriptive statistics for each trial of visuospatial working memory test across all groups.

	PK	No Overview		Overview	
		M	*SD*	*M*	*SD*
Overall	Low	14.25	3.45	14.20	3.00
	High	14.40	1.35	13.45	2.54
Forward	Low	7.44	2.00	7.13	1.36
	High	7.60	1.17	7.27	1.49
Reverse	Low	6.81	1.80	7.07	2.05
	High	6.80	.92	6.18	1.80

Pearson's correlations indicated that there was no significant relationship between visuospatial working memory and overall (p = .441), textual (p = .700), and integration (p = .474) comprehension. Additional correlations assessed the relationship between visuospatial working memory and comprehension for each group, finding no significant relationships.

To summarise the working memory results, neither verbal nor visuospatial working memory was related to comprehension scores. However, looking at each graphical overview group separately, the verbal working memory of those with an overview was positively correlated to scores on all three comprehension measures. Correlations found partial support for **H**$_3$; that higher verbal (but not visuospatial) working memory ability readers with an overview had the highest comprehension scores.

7.6.4 Confidence Ratings

The group with the highest average confidence ratings was high prior knowledge participants reading with a graphical overview (66.6%), whereas the group with the lowest confidence ratings was low prior knowledge participants with a graphical overview (40.4%). The average confidence ratings for participants in each reading condition were compared with their actual performance on the reading comprehension test (Figure 7.8).

For those reading with no graphical overview, both low and high prior knowledge participants reported lower confidence ratings than their actual performance on the comprehension test. This suggests an underconfidence of performance regardless of prior knowledge. For those reading with a graphical overview, low prior knowledge participants' confidence ratings also suggested an underconfidence. A two-way MANOVA was conducted the assess the effect of prior knowledge or graphical overview condition on average confidence ratings. Using Wilks' Lambda, there was a significant main effect of prior knowledge on confidence ratings, $F(20, 29) = 2.66$, $p = .008$, partial $\eta^2 = .647$. High prior knowledge participants reported higher average confidence ratings than those with low prior knowledge. There was no significant main effect of graphical overview condition on confidence ratings, $F(20, 29) = .85$, $p = .642$, partial $\eta^2 = .369$. However, those with high prior knowledge reported higher confidence ratings than their actual comprehension performance, suggesting an overconfidence. The results were not modified by an interaction effect of prior knowledge and graphical overview condition ($p = .312$).

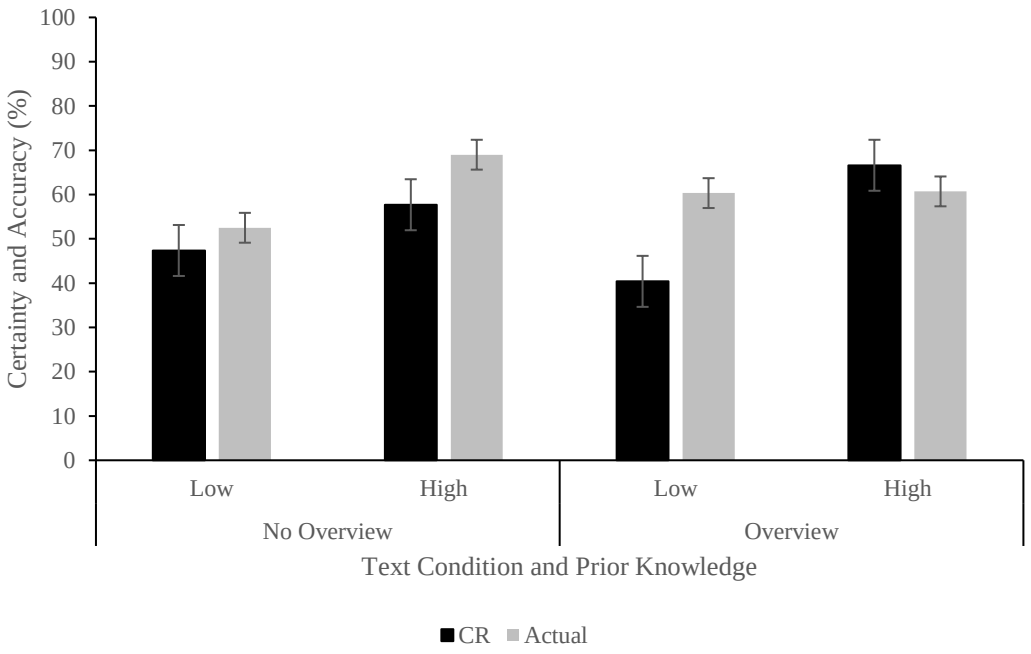


Figure 7.8. Average confidence ratings compared with actual performance accuracy across each condition.

7.6.5 Predictions, Interest, Effort (PIE)

Before taking part in the reading task, participants first completed the PIEpre questionnaire in which they were asked to predict how many answers they would get correct out of 20 on a comprehension test (M = 11.75, SD = 3.01) and, using a six-point scale, rate their interest in the topic (M = 4.31, SD = 1.06), predict how difficult it would be to learn the content of the text (M = 4.00, SD = .93), how difficult the test questions will be (M = 3.77, SD = 1.02), and how difficult it will be to learn from the medium of hypertext (M = 3.88, SD = 1.02).

After completing the reading task and the comprehension test, participants completed the PIEpost questionnaire in which they were asked the same questions. In addition to the above items, the PIEpre also included a question asking participants to consider how they prefer to learn new information and report whether

they prefer to read on paper, screen, or if they have no preference. Overall, 78.8% of all participants said they prefer to read on paper, compared to a 5.8% preference for reading on screen and 15.4% with no preference. The descriptive statistics for these items on the PIEpre and PIEpost questionnaires are displayed in Table 7.9.

Table 7.9

Descriptive statistics for PIEpre and PIEpost questionnaire measures.

Measure	Pre/Post	Overview and Prior Knowledge							
		No Overview				Overview			
		Low		High		Low		High	
		M	SD	M	SD	M	SD	M	SD
P (0-20)	Pre	11.06	2.89	12.90	2.77	11.20	2.93	12.45	3.59
	Post	7.75	3.99	10.40	4.01	7.07	3.71	11.18	4.24
I (1-6)	Pre	4.31	.79	5.20	.92	3.93	.96	4.00	1.26
	Post	4.00	1.15	5.50	.71	3.53	1.25	4.18	1.40
CD (1-6)	Pre	4.06	1.06	4.40	.52	3.87	.92	3.73	1.01
	Post	4.50	1.03	4.30	.95	4.87	.83	3.55	1.21
QD (1-6)	Pre	3.69	.95	4.30	.82	3.80	.86	3.36	1.12
	Post	4.50	.97	4.80	.63	4.73	.70	3.63	.92
HD (1-6)	Pre	4.06	.85	4.20	1.23	3.53	.99	3.82	1.08
	Post	4.13	1.54	5.20	.79	4.33	1.29	3.64	1.29

Note. **P** = Prediction; **I** = Interest; **CD** = Content Difficulty; **QD** = Question Difficulty; **HD** = Hypertext Difficulty.

A two-way MANOVA was conducted to assess whether reading condition or prior knowledge groups differed on PIEpre or PIEpost measures of predictions, interest, content difficulty, or question difficulty. Those without a graphical

overview reported their pre- and post-test interest in the topic as being significantly greater than those with a graphical overview. Those in the high prior knowledge group gave a significantly higher post-test comprehension score prediction (p = .004), and post-test topic interest rating (p = .002) than low prior knowledge participants. Low prior knowledge participants rated the content difficulty at post-test significantly higher than those in the high prior knowledge group (p = .010). A series of t-tests found that participants gave significantly lower post-test comprehension score predictions than their pre-test predictions (p < .001). Participants' post-test ratings of question difficulty (p < .001) and medium difficulty (p = .045) were significantly higher than their pre-test predictions (Table 7.10).

Post-test measures of question difficulty (p = .005) and hypertext difficulty (p = .020) were modified by interaction effects. Low prior knowledge participants with a graphical overview reported greater question difficulty than those without, whereas high prior knowledge participants with a graphical overview reported lower question difficulty than those without. Similarly, low prior knowledge participants with a graphical overview reported greater hypertext difficulty than those without, whereas high prior knowledge participants with a graphical overview reported lower hypertext difficulty than those without.

Table 7.10

Results of two-way MANOVA on PIEpre and PIEpost measures, with t-test.

Item	Pre /Post	Main Effects						*t*-test	
		Overview		PK		Overview*PK			
		F	*p*	*F*	*p*	*F*	*p*	*t*	*p*
P	Pre	.032	.950	3.24	.078	.115	.736	5.40	**< .001***
	Post	.002	.965	**9.08**	**.004***	.426	.517		
I	Pre	**8.14**	**.006***	2.97	.091	2.20	.145	1.00	.322
	Post	**7.25**	**.010***	**10.51**	**.002***	1.65	.205		
CD	Pre	2.74	.104	.143	.707	.827	.368	1.92	.060
	Post	.465	.499	**7.15**	**.010***	3.88	.055		
QD	Pre	2.40	.128	.110	.742	3.88	.055	4.05	**< .001***
	Post	3.92	.053	2.88	.096	**8.84**	**.005***		
HD	Pre	2.49	.121	.536	.468	.065	.799	2.05	**.045***
	Post	3.39	.072	.264	.610	**5.78**	**.020***		

Note. **P** = Prediction; **I** = Interest; **CD** = Content Difficulty; **QD** = Question Difficulty; **HD** = Hypertext Difficulty; ***** = significant at $p < .05$.

The PIEpost questionnaire contained one additional item which asked participants '…if you had been placed in the other reading condition (with or without graphical overview), do you think you would have performed better, worse, or the same as you did on the comprehension test?'. A chi-square test of independence assessed the relation between graphical overview and prior knowledge, finding no significant relation between these variables, $X^2(1, 52) = .080$, $p = .777$ (Table 7.11).

Table 7.11

Percentage (%) of participants in each reading condition who thought they would perform better, worse, or the same, on reading comprehension test if placed in alternative condition.

Actual Condition	PK	Alternative Condition					
		No Overview			Overview		
		Better	Worse	Same	Better	Worse	Same
No Overview	Low				87.5	0.0	12.5
	High				100	0.0	0.0
Overview	Low	6.7	80.0	13.3			
	High	0.0	72.7	27.3			

The association between participant's overall pre-test predictions of performance and their actual comprehension test score was tested (both out of 20). A Pearson's correlation revealed that, overall, there was no significant association between participants' pre-test predictions (M = 11.75, SD = 3.05) and their final comprehension test scores (M = 12.81, SD = 3.31), $r(52) = .228$, $p = .104$. Therefore, participants across all conditions were generally inaccurate at predicting how many questions they would answer correctly before they took part in the

reading task. In order to assess calibration bias**,** the correspondence between participants' post-test predictions and their actual comprehension test score (both out of 20) was examined. A Pearson's correlation revealed that, overall, participants' post-test predictions (M = 8.79, SD = 4.23) were significantly correlated with their final comprehension test scores (M = 12.81, SD = 3.31), $r(52) = .665$, $p < .001$. Therefore, participants were generally accurate at predicting how many questions they had answered correctly out of 20 after having completed the comprehension test.

There was an underconfidence in pre-test predictions across all groups except for low prior knowledge participants without a graphical overview, who gave a higher average prediction compared to their actual comprehension score. There was also an underconfidence in post-test predictions, as these scores were lower than actual comprehension scores across all groups. Post-test predictions were lower than pre-test predictions across all groups, meaning that participants thought they had answered fewer questions correctly after completing the comprehension test than they had predicted they would beforehand (Figure 7.12).

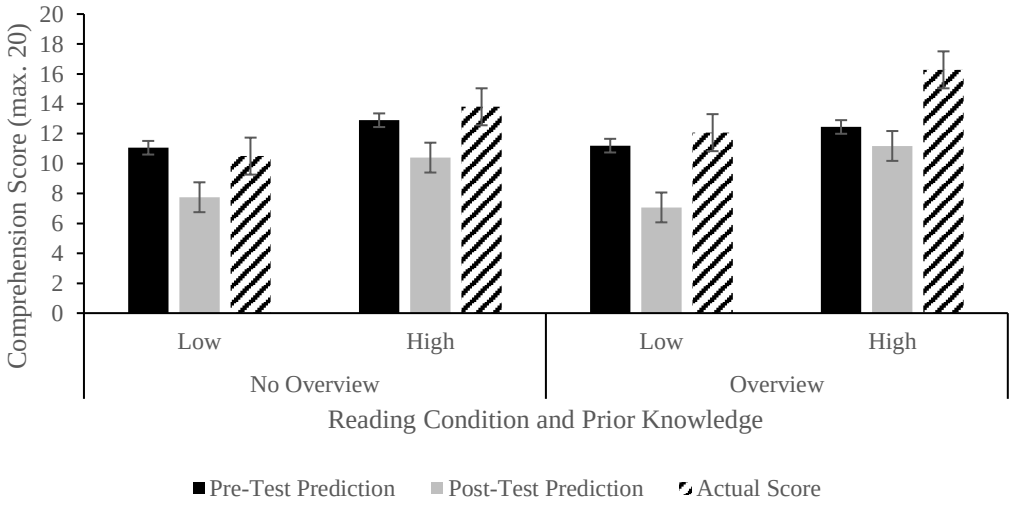


Figure 7.12. Mean pre and post-test comprehension predictions and actual scores.

7.6.6 Reading Strategies

A two-way between subjects MANOVA was conducted to assess whether low and high participants reading from hypertext with or without a graphical overview differed on responses to items 1-12 of the reading strategies questionnaire. There was a significant main effect of graphical overview condition on responses to items six ('I kept the aim of the task in mind when reading through the text'), p = .039; seven ('I became lost/confused when reading through the text') p = .014; nine, ('I took the time to become familiar with the website's layout before I read the information'), p = .0139; and 12 ('I used the pictures to help me navigate through the text'), $p < .001$. Those reading with a graphical overview reported that they kept the aim of the task in mind, took the time to become familiar with the website's layout, and used the pictures to help them navigate more than those reading without a graphical overview. Those reading without a graphical overview became lost and confused when reading through the text more than those reading with an overview.

There was also a significant main effect of prior knowledge on responses to items one ('I tried to find connections between different parts of the text'), p = .019; four ('I revisited pages which contained information I found difficult to remember'), p = .007; and five ('I found it easy to locate pages I wanted to revisit'), p = .020. High prior knowledge participants indicated that they tried to find connections, and revisited pages they found difficult to remember more than the those with low knowledge. Alternatively, low prior knowledge participants reported that they found it easier to locate pages they wanted to revisit than the high knowledge group. There was no interaction effect (p = .770).

Of the 1-12 statement items, the most preferred strategies were to 'revisit pages which contained information I found difficult to remember" (M = 4.81, SD = 1.37), and to "try to find connections between different parts of the text" (M = 4.27, SD = 1.37). The least preferred strategies were to take the time to "become familiar with the website's layout before I read the information" (M = 1.87, SD = .97), and to "use the pictures to help me navigate through the text" (M = 2.35, SD = 1.56). Of the remaining reading strategy items which had multiple options to choose from, the most popular strategy when first opening the webpage was to start reading immediately (87%).

When encountering a new section, participants mainly started reading immediately (81.1%), when encountering a new hyperlink they clicked it after finishing reading the page (67.3%). On sections with more than one hyperlink, readers mainly clicked the one that had appeared first (80.8%), and then continued through the text from the page the link had sent them to (73.15%). Participants reported that sections with pictures on were more interesting (41.1%), that they skim-read through as much of the text as they could once they were sure they had read all of the sections (48.5%), and used the reading time to spend longer on pages where the information was more difficult to learn (43.1%). Table 7.13 shows the mean scores for items 1-12, and Table 7.14 shows the percentage of participants who selected each of the options for items 13-20.

Table 7.13

Overall scores for items 1-12 of reading strategies questionnaire, in order of average scores.

Question Number	Description	*M*	*SD*	*p*	
				Overview Condition	Prior Knowledge
4	'Difficult information'	4.81	1.37	.881	.007*
1	'Connections'	4.27	1.37	.816	.019*
3	'Stopped to read through'	4.06	1.51	.690	.958
6	'Aim of task in mind'	3.77	1.48	.039*	.751
2	'Memorised separately'	3.46	1.70	.112	.858
7	'Became lost/confused'	3.37	1.58	.014*	.988
5	'Easy to locate sections'	3.08	1.57	.470	.020*
11	'Felt time pressure'	2.87	1.40	.730	.218
8	'Beginning, middle, end'	2.52	1.65	.266	.227
10	'Was strategic in time'	2.48	1.38	.817	.573
12	'Used pictures'	2.35	1.56	< .001*	.307
9	'Became familiar'	1.87	0.97	.039*	.469

***** significant at $p < .05$.

Table 7.14

Proportion of participants who selected each of the options for items 13-20 of reading strategies questionnaire (%).

Question Number	Statement	Options	Total	Overview/Prior Knowledge			
				No Overview		Overview	
				Low	High	Low	High
13	'First opened…'	Read immediately	87.0	88.9	80.0	86.7	90.9
		Relevant	7.4	11.1	10.0	6.7	0.0
		Became familiar	5.6	0.0	10.0	6.7	9.1
14	New section	Read immediately	81.1	76.5	100	80.0	63.6
		Relevant	18.9	23.5	0.0	20.0	27.3
15	New hyperlink	Relevant to goal	26.9	25.0	30.0	26.7	27.3
		Clicked immediately	3.8	6.3	10.0	0.0	0.0
		Clicked after reading	67.3	68.8	60.0	66.7	81.8
		Clicked after sentence	1.9	0.0	0.0	6.7	0.0
16	1+ hyperlink	Clicked first one	80.8	100	90.0	60.0	72.7
		Clicked last one	5.8	0.0	10.0	40.0	18.2
17	After clicking hyperlink	Continued though	73.1	68.8	50.0	87.7	81.8
		Went back	25.0	31.3	50.0	13.3	18.2

Question Number	Statement	Options	Total	Overview/Prior Knowledge			
				No Overview		Overview	
				Low	High	Low	High
18	Picture	More relevant	8.9	12.5	10.0	5.3	9.1
		More interesting	41.1	37.5	70.0	31.6	36.4
		Easier to learn	26.8	18.8	10.0	78.9	27.3
		Easier to locate	17.9	25.0	10.0	10.5	27.3
		Spent longer on page	5.4	6.3	0.0	5.3	0.0
19	After reading	Stopped reading	1.9	0.0	0.0	6.3	0.0
		Re-read sections	40.7	25.0	45.5	43.8	54.5
		Skim-read through	57.4	75.0	54.5	50.0	54.5
20	Use of time	Equal time on pages	8.6	0.0	10.0	12.5	14.3
		Difficult pages	43.1	33.3	30.0	56.3	50.0
		Left time to revisit	15.5	5.6	30.0	6.3	21.4
		Quickly as possible	15.5	33.3	20.0	0.0	7.1
		Did not think	17.2	22.2	10.0	18.8	7.1

7.6.7 Graphical Overview Usage

A one-way MANOVA was conducted to assess whether low and high prior knowledge participants differed on responses to items 1-12 of the graphical overview usage questionnaire, finding a significant main effect of prior knowledge on responses to item 11 ('I used the overview to help me decide which hyperlink I should click on next'), $p = .016$. Low prior knowledge readers used the overview to help them decide which hyperlink they should click on next more than high knowledge readers. Overall, participants reported that the overview was most helpful for identifying which page they were currently on ($M = 4.62$, $SD = 1.39$), and making it easy to identify which pages they could navigate to from the one they were currently on ($M = 4.42$, $SD = 1.50$). However, it was reported that the overview was least helpful for distinguishing between the beginning, middle and end of the text ($M = 2.50$, $SD = 1.73$), and helping them to decide which pages were more relevant to their reading goal ($M = 2.54$, $SD = 1.56$; Table 7.15).

Table 7.15

Overall scores for items 1-12 of graphical overview usage questionnaire (1-6), in order of average scores.

Question Number	Description	*M*	*SD*	*p*
				Prior Knowledge
9	'Identify current page'	4.62	1.39	.440
10	'Which pages to navigate'	4.42	1.50	.344
2	'Helped relocate'	4.00	1.65	.482
3	'Make connections'	4.00	1.79	.386
1	'Made use'	3.81	1.72	.268
4	'Looked at first'	3.38	1.68	.958
7	'Less lost/disorientated'	3.35	1.70	.384
11	'Which hyperlink to click'	3.27	1.87	.016*
6	'Relevant pages'	2.54	1.56	.633
8	'Beginning, middle, end'	2.50	1.73	.310
5	'How much time'	2.23	1.53	.522

***** significant at $p < .05$.

7.6.8 Navigation Behaviour

The hypothesis **H_4** predicted that more strategic and knowledge-seeking navigational behaviours would be positively related to comprehension scores, whereas non-strategic and feature-seeking behaviours would be negatively related.

Average Time Spent Per Page

A two-way between subjects ANOVA was conducted to assess whether there was an effect of graphical overview or prior knowledge on average time spent per page (scored as previously described; Table 7.16). There was a significant main

effect of prior knowledge on overall average seconds per page, $F(1, 48) = 5.97$, $p = .018$, partial $\eta^2 = .111$, with low prior knowledge participants spending a greater overall average number of seconds per page than high prior knowledge participants. There was no significant main effect of graphical overview on overall average seconds per page, $F(1, 48) = .000$, $p = .998$, partial $\eta^2 = .000$. Participants with a graphical overview spent a similar overall average number of seconds per page as those without a graphical overview. There was no interaction of prior knowledge and graphical overview, $p = .588$.

Table 7.16

Average time (seconds) per page for high and low prior knowledge hypertext readers with and without graphical overview.

Reading Condition	PK	*N*	Average Time Spent Per Page	
			M	*SD*
No Overview	Low	11	112.25	15.67
	High	10	101.70	7.41
Overview	Low	15	110.33	14.38
	High	16	103.64	6.33
Overall	Low	26	111.32	14.84
	High	26	102.71	6.76

'Clicking' Behaviour

A two-way between subjects ANOVA was conducted to assess whether there was an effect of prior knowledge or graphical overview condition on number of clicks made (Table 7.17). There was no significant main effect of prior knowledge

on number of clicks, $F(1, 48) = 1.55$, $p = .219$, partial $\eta^2 = .031$. There was a significant main effect of graphical overview condition on number of clicks, $F(1, 48) = 5.31$, $p = .026$, partial $\eta^2 = .100$, where those without a graphical overview made a greater number of clicks than those with an overview. There was no interaction effect ($p = .772$).

Table 7.17

Average number of clicks made by high and low prior knowledge hypertext readers with and without graphical overview.

Reading Condition	Prior Knowledge	*N*	Average Number of Clicks	
			M	*SD*
No Overview	Low	16	35.31	14.55
	High	15	39.20	14.93
Overview	Low	11	24.73	14.50
	High	10	31.00	13.51
Overall	Low	26	30.19	15.26
	High	26	34.90	14.46

Page Visits

The data relating to number of page visits are shown in Table 7.18. A two-way between subjects MANOVA was conducted to assess whether there was an effect of prior knowledge or graphical overview condition on overall number of visits per page. There was no significant main effect of prior knowledge on number of visits ($p = .981$). There was a significantly main effect of graphical overview condition on number of visits ($p = .001$), with readers without a graphical overview

generally visiting pages a greater number of times than those with an overview. There was no interaction effect (p = .607).

Table 7.18

Average page visits across all groups.

Page Number	PK	Graphical Overview			
		No Overview		Overview	
		M	*SD*	*M*	*SD*
1.0	Low	7.44	3.42	4.67	2.64
	High	8.30	3.27	4.91	2.70
1.1	Low	3.88	2.16	2.27	1.03
	High	4.50	2.17	2.64	1.63
2.0	Low	3.44	2.00	2.40	1.24
	High	3.80	2.30	3.36	1.75
2.1	Low	1.63	1.96	2.20	1.61
	High	2.80	1.55	2.55	1.44
2.2	Low	.94	1.34	2.27	2.15
	High	1.40	1.43	2.45	1.21
3.0	Low	2.38	1.75	1.33	.90
	High	2.50	1.43	1.91	.83
3.1	Low	2.19	1.60	1.60	1.35
	High	2.70	1.16	1.36	.92
3.2	Low	2.25	1.48	.73	.80
	High	1.70	.67	1.09	.83
4.0	Low	3.00	1.75	2.13	1.51
	High	3.50	2.64	3.55	2.34
5.0	Low	2.88	1.89	1.87	1.55
	High	3.50	2.17	2.18	1.08
6.0	Low	2.88	1.50	2.40	1.45
	High	2.80	1.40	2.82	1.54
6.1	Low	2.00	1.15	1.93	1.94
	High	2.10	.88	2.09	1.04

Pearson's correlations were conducted to assess whether there was a relationship between total number of clicks or average seconds spent per page, and overall, textual, and integration comprehension performance. There was no significant association between total number of clicks and overall, $r(52) = -.013$, p =

.927; textual, $r(52) = .132$, $p = .349$; and integration comprehensions scores, $r(52) = -.154$, $p = .277$.

Navigation Styles

Readers' navigation behaviour was investigated to see whether they could be grouped into different types of navigational styles. On average, participants spent 108 seconds per page, made 32 clicks, and scored 13 out of 20 on the reading comprehension test. Table 7.19 shows an overview of the strongest and weakest performers in each group including an interpretation of whether their navigation activities were beneficial for comprehension. The selected participants were representative of other participants with high and low comprehension scores in each group.

Table 7.19

Overview of strongest and weakest hypertext performers.

Graphical Overview	Score	PK	Clicks	Secs. Per Page	Navigation Summary	Interpretation
No Overview	7	Low	39	107	- First half of reading time spent on first 3 pages they encountered. - Several periods of multiple clicks in quick succession, accessing multiple pages.	- Absence of overview meant the reader was clicking through the text trying to locate unread pages, resulting in 'wasted' time.
	17	High	36	106	- Visited all pages within first 10 minutes. - 'Review' period in final 5 minutes where pages first viewed early on were revisited.	- Initial familiarisation period to build macrostructure representation beneficial for comprehension.
Overview	7	Low	14	107	- Only made four revisits to previously read pages. - Only one page was unvisited. - They did not leave any time for a review period towards the end of the reading time where they could revisit the most difficult sections.	- Overview ensured most pages were visited, but a low number of page revisits and poor time-management detrimental to comprehension
	18	High	21	96	- Visited each section of the text at least once. - Made many revisits to previously read pages, especially during final five minutes.	- A high number of page revisits, especially during final five-minute period) and high seconds per page was beneficial.

7.6.9 Comparative Impact of Measures

A multiple regression was calculated to predict comprehension based on the independent measures of graphical overview usage, prior knowledge (familiarity scores), working memory (verbal and visuospatial scores), reading strategies (total score on first 12 items of reading strategies questionnaire), and navigation (average time spent per page). The model was significant, and the four variables together accounted for 26% of the variance in comprehension performance, $F(6, 45) = 6.620$, $p < .001$, $R^2 = 469$ (Table 7.20). Only graphical overview ($p < .001$) and prior knowledge ($p = .006$) made significant unique contributions. The best predictor of comprehension was graphical overview ($\beta = .543$) followed by prior knowledge ($\beta = .334$).

Table 7.20

Results of multiple regression.

Predictor	*B*	*SE B*	*β*	*t*	*p*
Overview	2.163	.450	.543	4.807	**.001***
PK	.673	.235	.334	2.866	**.006***
Verbal WM	.344	.224	.171	1.536	.132
VS WM	.005	.225	.003	.023	.982
Strategies	.017	.228	.009	.076	.940
Navigation	.175	.241	.087	.723	.473

***** significant at $p < .05$.

7.7 Discussion

The present study aimed to explore the effect of a graphical overview on the comprehension and navigation of hypertext in low and high prior knowledge students. It also assessed students' working memory, metacognitive experience, and reading strategies. The main findings related to these measures will be discussed in this section. In addition, potential methodological limitations will be considered and directions for future research in this area will be recommended. Implications of these findings will be discussed in more detail in Chapter 8. Table 7.21 includes a brief summary of the main results of this experiment.

Table 7.21

Results summary.

Variable	Key Findings
Familiarity	- High prior knowledge group had highest familiarity scores.
Reading Comprehension	- Those with a graphical overview performed significantly better than those without for overall and inferential comprehension. - Those with high prior knowledge performed significantly better on overall, textual, and inferential comprehension than those with low prior knowledge.
Confidence Ratings	- High prior knowledge participants with a graphical overview gave the highest confidence ratings, whereas those with low prior knowledge and without an overview gave the lowest.
Working Memory	- No relationships between verbal or visuospatial working memory and overall, textual, and inferential comprehension between groups.
Predictions, Interest, Engagement	- Overall preference for learning from print versus digital texts. - Those with an overview said they would have performed worse without an overview, and those without said they would have performed better with one.
Reading Strategies	- Those without an overview reported greater disorientation than those with an overview. - Those with high prior knowledge tried to find connections, whereas those with low prior knowledge found it easier to relocate pages they wanted to revisit.
Graphical Overview Usage	- Overall, overview most useful for identifying connections between pages.
Navigation	- Graphical overview supported navigation (e.g., fewer clicks, initial familiarisation period).

The primary aim of the present experiment was to explore the effect of a graphical overview on hypertext learning. It was predicted that those with a graphical overview would score higher than those without (**H_1**). In support of this prediction, those with a graphical overview scored higher on overall and inferential measures of comprehension than those without. The same was found for both low and high prior knowledge participants. Although there were no differences between groups for textual comprehension, readers without a graphical overview scored lower on inferential comprehension items. This may be due to navigational difficulties meaning that it is not easy for learners to identify how the information is related across pages.

As previous research has shown, hypertext readers frequently report disorientation and difficulties in locating/relocation information. This is likely due to readers having difficulty in constructing an accurate representation of the organisational structure of the text. This experiment did not find support for the Active Processing model's claim that overviews may be detrimental for comprehension as they limit the discovery of relations between texts parts. Instead, this experiment found support for the Assimilation theory, which proposes that overviews provide an organisational framework which enable readers to construct an accurate macrostructure representation, improving comprehension. Supporting the construction of an accurate representation of organisational text structure frees up cognitive resources for deep comprehension processes like inferencing and connecting ideas. This may explain why there were higher integration comprehension scores for those with an overview than those without.

7.7.1 Role of Prior Knowledge and Working Memory

In the present study, it was predicted that those with high prior knowledge would score higher on comprehension than those with low prior knowledge (**H_2**). As expected, overall, high prior knowledge participants scored higher on all three measures of comprehension (overall, textual, integration) than those with low prior knowledge. This supports the findings of Potelle and Rouet (2003), who suggested that hyperlinks in networked hypertexts require inferences that are beyond the ability of low knowledge readers. High knowledge readers are at an advantage when deciding which hyperlinks to select because they can make more accurate judgements as to whether the hyperlink will lead to information relevant to their reading goal. The finding from the correlational analysis that lower working memory ability readers were especially disadvantaged when learning hypertext without an overview, supports the suggestion that low prior knowledge participants may need an explicit representation of structure so that they can focus more on learning the information rather than constructing a situation model as well as engaging in learning processes.

While low prior knowledge participants reported greater disorientation than those with high knowledge, less disorientation was reported by low knowledge participants with a graphical overview. This suggests that having an overview is particularly beneficial for low knowledge readers of networked hypertexts. An explanation for this may be that low knowledge readers find it difficult to manage the two tasks of building a coherent mental representation of the text while also engaging in comprehension processes.

Correlational analyses found partial support for the prediction that higher working memory ability readers with an overview would have the highest comprehension scores (**H_3**). While verbal working memory was positively related to comprehension in readers with an overview, there was no correlation between visuospatial working memory and performance. An explanation for this is that learning in networked hypertext is so challenging for readers, that higher visuospatial working memory alone is not enough to overcome the disadvantages of reading this format, even with an overview. This is due to the frequent disruption to the storage and manipulation of visuospatial information by hyperlink and organisational representation processing (DeStefano & LeFevre, 2007). Instead, a combination of high prior knowledge, higher working memory ability, strategic navigation, *and* overview, provides the best opportunity for hypertext readers to gain good comprehension. This is supported by the regression analysis which found that prior knowledge and graphical overview are the strongest predictors of comprehension in hypertext, whereas verbal and visuospatial working memory ability alone are not significant predictors of performance.

7.7.2 Individual Differences in Navigation Behaviour

Previous research has suggested that in order to navigate efficiently, hypertext readers elaborate the mental representation of text layout and content structure. Networked hypertexts have a particularly complex layout which may increase disorientation, impair performance, and inhibit the ability to navigate strategically. Graphical overviews display the topographical structure of the text in addition to the relations between pages and navigation pathways, and have been shown to facilitate navigation. As a result, it was predicted that those with an

overview would visit more pages, spend a shorter amount of time on page, engage in more strategic navigation behaviours, report less disorientation, and rate the medium learning difficulty lower versus those without (**H_4**).

Those reading hypertext without an overview visited more pages but spent shorter average time spent per page than those with an overview. This supports others' findings that readers go back and forth between hypertext pages more often when no clear text structure is available (Blom et al., 2018). This indicates that readers attempt to make sense of the structure of the text before reading. Indeed, Fitzsimmons and colleagues (2016) identified that young adult readers engage in three stages when reading a hypertext: first they scan the page very quickly at bottom and top, then they check whether there are hyperlinks present, and finally they scan the page again to choose which hyperlink to click on. This follows earlier work which found that hypertext readers use the home page as a landmark, especially when the global structure is confusing or complex (Britt et al., 1996). This may explain why those without an overview visited the first page of the hypertext more often than those without in the present study; they may have been attempting to identify a landmark from which to navigate to other pages.

Overall, participants reported that the graphical overview was most helpful for identifying which page they were currently on, which pages they could navigate to from each page, and for making it easy to distinguish between the beginning, middle, and end of the text. Conversely, those without an overview reported they became lost and confused while navigating. This demonstrates the benefits of having a graphical overview for navigating hypertext.

7.7.3 Implications and Directions for Future Research

The findings of this experiment offer an optimistic view of the future of digital reading. While there are some disadvantages of learning from and navigating through hypertext, novel facilitatory aids can benefit those most affected by these disadvantages. In particular, low prior knowledge learners can benefit from having a graphical overview which shows the topological structure of the hypertext and the connections between its pages. An overview that highlights which page the reader is currently located on allows readers to identify the navigation pathways available to them via hyperlinks. This helps reduce disorientation, improves germane cognitive load, reduces extraneous cognitive load, and facilitates comprehension. For example, the presence of a graphical overview was found to be beneficial for inferential comprehension in both low and high prior knowledge participants, showing that all readers can have some benefit from reading hypertext with a graphical overview of this type.

A potential limitation of this experiment is that participants may have had no previous experience of graphical overviews, meaning some of their reading time may have been spent learning how to use it rather than learning the information. While there was a brief familiarisation period before the reading task during which the experimenter demonstrated what the graphical overview looked like, it may have taken some readers time to integrate the overview into a coherent mental representation of the organisational structure of the text. Prior training on how to use graphical overviews may have supported readers in their use of the overview to navigate.

Other individual differences not assessed in the present study may influence the navigation behaviour of hypertext readers. For example, studies have found that high visualisation ability may lead to improved navigational performance in hypertext reading (Downing et al., 2005; Nilsson & Mayer, 2002; Zhang & Salvendy, 2001). Furthermore, eye-tracking and think-aloud protocols may help to elucidate how readers interact with graphical overview during reading tasks.

Chapter 8: Discussion

8.1 Revisiting Thesis Aims

With digital text reading becoming increasingly prevalent for both recreation and education while print text reading is declining, a need for further research exploring the differences between study media was identified. Questions remained about how students' prior knowledge, working memory ability, and metacognitive experience are related to their navigation and comprehension of hypertext. In addition, if disadvantages of learning from hypertext existed, how might they be overcome? Therefore, the motivation of this thesis was to explore how students learn from hypertext, and how this is different to learning from print text. It also sought to illuminate how students navigate hypertext and to better understand the relationship between multiple factors including individual differences, reading conditions (e.g., time pressure), and reading comprehension.

It was acknowledged that even if the results of this thesis agreed with previous research that differences between study media did exist, it is unlikely that in the future texts would revert from screens back to paper. Technological advancements (e.g., e-readers, computers, mobile phones) have made digital texts available and affordable for most people, and the incidence of reading and learning on screen is increasing rather than decreasing. Thus, this thesis set out to better understand the processes involved in digital text learning, how this differs from print text, and to shed some light on unanswered questions in this area which may be of benefit to web designers, educators, and readers themselves.

Overall, the thesis was successful in meeting these aims. To achieve them, interactive and controlled hypertext environments for participants to read and

navigate through were designed. This allowed for the exploration of participants' activity during reading, including how they interacted with hyperlinks and how they used their time. The expository texts created were presented to participants in a range of print and digital text formats, including print text, scrolling text, structured hypertext, and networked hypertext. This allowed for the assessment of learning across study media. Multiple questionnaires were administered to measure factors including reading comprehension, reading strategies, and metacognitive experience across four original empirical experiments. Each of these experiments addressed different questions related to how students learn from and navigate hypertext. In doing so, this thesis made the following unique contributions:

- Explored the screen inferiority effect by comparing university students' comprehension and navigation of multiple digital and print text mediums using the same expository text.
- Suggested navigation, working memory, and prior knowledge have the greatest impact on comprehension of hypertext.
- Indicated a dynamic graphical overview facilitates navigation and comprehension in networked hypertext.

This chapter will synthesise the findings of these experiments, and explore how they have contributed to both the overall aims of the thesis and, more broadly, to the field of hypertext navigation and comprehension. Limitations of the present research are considered in addition to potential future directions in this area. Table 8.1 shows a brief overview of the experiments conducted as part of this thesis and their key findings.

Table 8.1

Research overview.

Study	Title	*N*	Text Topic	Study Media	Key Findings
1	How metacognitive experience and working memory are related to navigation and comprehension of hypertext.	54	Battle of Trafalgar	- Print Text - Scrolling Text - Structured H'text - Networked H'text	- No effect of study media on comprehension. - Verbal working memory positively related to comprehension. - Spending greater time on hypertext pages positively related to comprehension.
2	The effect of study time pressure on comprehension and navigation of hypertext.	90	Battle of Trafalgar	- Print Text - Scrolling Text - Structured H'text - Networked H'text	-No main effects of time pressure across study media but print readers most efficient. - Advantages for print and scrolling text versus hypertext.
3	Learning from hypertext: prior knowledge, comprehension, and navigation.	52	Working Memory	- Print Text - Scrolling Text - Networked H'text	- Disadvantage of hypertext for inferential comprehension. - Disadvantages of hypertext for low knowledge readers.
4	Overcoming disadvantages of hypertext: does a graphical overview facilitate navigation and comprehension?	52	Working Memory	- Networked H'text	- Graphical overview facilitated navigation and comprehension of hypertext. - Overview particularly beneficial for low knowledge hypertext readers.

8.2 General Evaluation Points

The main objective of the thesis was to explore how students learn across study media. Previous research has generally found an advantage of linear texts over hypertexts for comprehension (DeStefano & LeFevre, 2007). While multiple studies have investigated differences between print text and different types of (e.g., Amadieu et al., 2010; Blom et al., 2018; Lee & Tedder, 2004; Potelle & Rouet, 2003), it was identified that no studies had yet explored the comparative impact of print text to linear versus non-linear digital texts considering multiple relevant variables such as time pressure, prior knowledge, and type of comprehension (textual versus inferential). Furthermore, while Salmerón and colleagues' work on hypertext comprehension has identified screen inferiority effects in children, the current work elaborates on the comparative cognitive processes involved in hypertext and print text reading in university students, and how to overcome the screen inferiority effect. This section will evaluate some of the experimental design decisions made throughout this thesis, including why certain types of text were used, the differences between the two text topics, and alternative methodological approaches.

8.2.1 Methodological Approach

The comprehension of print text, scrolling text, structured hypertext, and networked hypertext was assessed. Scrolling text was not considered a digital equivalent to print text; instead, it was considered a digital text with a linear structure but without the additional processing demands posed by hypertexts (i.e., presence of hyperlinks). Both structured and networked hypertext were utilised in the thesis to explore the impact of different types of hypertext on navigation and comprehension. Networked hypertexts are considered more complex than structured hypertexts

because they typically contain a network of highly interconnected pages that do not follow any particular order. The decision was made to design the hypertext environments rather than use existing informational websites to provide control over the number and location of hyperlinks, how the pages were interconnected, and in what order the information was presented. Two distinct types of hypertext were created and it was ensured that the content was same for each study medium, improving the ability to make comparisons between groups.

A potential limitation of designing the texts in this way is that they may not have accurately reflected the kinds of texts students use to learn from in 'real life' contexts. While the text content came from real online educational resources, the location of hyperlinks and interconnections between pages were contrived, and their location may have impacted reading processes by appearing in atypical sentence or page locations. On the one hand, some websites are deliberately organised by experienced web designers, who may consider the location of hyperlinks when determining user readability. On the other hand, the organisational structure and location of hyperlinks in some websites (e.g., Wikipedia articles) is less deliberate, with a focus on including as much information as possible rather than user readability. Therefore, while the texts in the present research may not accurately be compared to any one educational resource, students are accustomed to learning from a variety of texts each with different challenges to reading, so the results are still generalisable to real learning contexts.

Another possible limitation of presenting the same text across both print and digital formats, is that the information may not have been suitable to be presented in both formats. The first text topic of the Battle of Trafalgar was suited to being presented on both print and digital text because it followed a linear chronology/story

which had a beginning, middle, and end. However, there were greater difficulties creating a chronological structure for the print text version of the working memory text in the third experiment, as the information consisted of multiple sections which did not necessarily follow on from each other. Therefore, print text readers may have navigated between pages in any order rather than read from left to right, as expected in a linear text format. If print text readers did navigate in this way, then it would challenge the conclusion that the nonlinearity of hypertext is responsible for comprehension differences between study media. In mitigation of this risk, the reading strategies questionnaire revealed that print text readers in the third experiment found it easier to distinguish between the beginning, middle, and end of the text than hypertext readers, suggesting text structure may indeed be partly responsible for comprehension differences.

An alternative methodological approach would have been to administer pre-existing materials rather than creating original questionnaires and texts. For example, Salmerón and colleagues' (2018) developed the 'WebReading-S' set of materials to measure comprehension-based internet reading skills. The WebReading-S includes four web scenarios and 36 comprehension questions related to reading activity (retrieval, integration, and evaluation) in Google, Forum, Wikipedia, and a Web portal. This method would have been useful for assessing different levels of comprehension in one type of hypertext. However, the present research was interested in exploring differences between different types of print and digital texts. The current approach allowed for the design of different types of hypertext that closely matched the descriptions of structured and networked hypertext, which was useful for making the results more applicable to a range of hypertexts students might encounter in real life.

The present methods found expected results based on the theoretical background, and designing original questionnaire items enabled greater links to be made between the measures, including between hyperlink selection behaviour in the reading strategies questionnaire and navigation activity described in the log file information. Therefore, there was strong justification for choosing this approach. Future investigators may also wish to design their own questionnaires (in particular, websites and comprehension tests) to have greater control over reading conditions and comprehension measures. However, researchers should be cautious when designing questions which assess both textual and inferential comprehension; it was a challenge in this thesis to create inferential questions which measured deep learning (e.g., inference-making, evaluating), rather than an extension of textual learning which is still at a shallow level of processing (i.e., basic recall of two separate pieces of information). Furthermore, the experiments revealed that readers sometimes miss information, either intentionally or unintentionally, when navigating hypertext, so task instructions should make it clear that all information should be read (if appropriate to the task).

The present research made use of independent groups in all experiments. This design was the most useful for assessing differences between participants across several experimental conditions. Alternatively, a repeated measures design may be useful for future experiments investigating whether participants adapt their reading and navigation strategies based on their previous comprehension performance. For example, many participants across all experiments reported they had visited all the pages in the hypertext condition. However, analysis of their navigation behaviour found many participants did not visit some pages. If participants were made aware of this, they may employ different (i.e., more strategic) navigation behavior when

learning from hypertext in the future to ensure they do not miss pages. If this result is found, it would lend support for brief strategy training methods to overcome disadvantages of learning from hypertext.

Previous research has consistently found that media effects (i.e., screen inferiority) are present only for expository hypertext rather than other types of hypertext (for review, see, Delgado et al., 2018). An alternative type of hypertext is narrative hypertext. However, these are not very popular among readers and others have highlighted the challenges of assessing comprehension in this format (Mangen & van der Weel, 2017). The expository text used in the first two experiments was about a historical topic, the Battle of Trafalgar. This topic was utilised because it followed a natural chronology and had a number of distinct subsections; the information firstly described the background to the battle, then proceeded to describe the events during the battle, and finally presented the events following its conclusion. This meant that it was well suited to being presented both as a linear text (print and scrolling text) and as non-linear hypertext (structured hypertext and networked hypertext; text sections became individual webpages connected by hyperlinks).

Feedback from participants across the two experiments in which this text was used reported very low interest in the topic. While some researchers have indicated that topic interest is not related to comprehension of hypertext (Conradty & Bognerm 2016; Lawless et al., 2003), others have found that having low topic interest increases undesirable reading behaviour including mind wandering and lack of motivation (Unsworth & McMillan, 2013). Because topic interest was low in our first two experiments, this may have resulted in participants not being motivated to score higher on the comprehension test. This may explain why there were no significant differences in comprehension across study media in these experiments.

However, interest ratings significantly increased when measured post-test, indicating that participants were engaged during the reading task. Similarly, post-test reading difficulty ratings were lower than pre-test reading difficulty predictions, suggesting that participants thought the text was going to be more difficult to read than it was. Therefore, there was justification for the retention of the text in the second experiment because there was confidence that participants' initial low topic knowledge did not impact the post-test measures. Moreover, it was of interest to assess differences between study media on both textual and inferential comprehension using the same text in a subsequent experiment.

In the subsequent two experiments, the text was about working memory. This text was used because it could also be subdivided into multiple distinct sections to be presented as both a print text and hypertext; it also enabled the assessment of the impact of prior knowledge in our sample of Psychology students at different academic levels. Interest in this topic was higher than the first text among participants and there was a reduction in apathetic navigation behavior in these experiments (e.g., fewer unvisited pages and greater time spent per page). While an increase in topic interest may have played a role in the decrease of apathetic navigation in the third and fourth experiments, an alternative explanation may be that participants were more motivated to perform well because of the Psychology-related topic.

Most of the participants in these experiments were first-year Psychology undergraduates whose first experience of participating in psychological research was in these experiments. Therefore, they may have employed greater mental effort to learn from the Psychology-related topic because of a perceived expectation that they should know at least some of the information. University students are likely to be

motivated to succeed and interested in the topic when engaging in a reading task for their academic course. However, this motivation and interest may vary between readers depending on which module or topic they are learning. Readers with low interest can be motivated by the desire to succeed and achieve a good grade so engage in deep comprehension processes. The current experiments could have administered an independent measure of readers' motivation to achieve a good comprehension score.

The challenges of recruiting participants for some of the studies described in this thesis resulted in small subgroups, particularly for studies one and two. Consequently, the explained variance of the multivariate tests reported (e.g., Wilks Lamda) should be interpreted cautiously, as the proportion of variance in dependent variables explained by multivariate models' effects is typically more biased when the sample is small (Kenward & Roger, 1997). Although the function of a MANOVA test is to control the overall Type I error rate, previous research has found that many popular MANOVA-protected multiple-comparison procedures do not control for the maximum familywise error rate (Bird & Hadzi-Pavlovic, 2013). While post-hoc tests including LSD, Bonferroni, and Tukey's tests in addition to calculating the observed power of each MANOVA were calculated, a more robust approach would have been to provide the differences between the estimated power sample size (based on the effect sizes of previous studies with similar sized groups) and actual sample size.

8.2.2 Assessing Time Pressure

Previous research has found that a relevant moderator for the screen inferiority effect is time pressure (i.e., the amount of time allocated to the reading

task; Ackerman & Lauterman, 2012; Delgado et al., 2018; Sidi et al., 2017). Therefore, the second experiment introduced levels of time pressure during the reading task (none, moderate, high). However, no time pressure-related effects on learning across study media were found. An improvement of this method could have been to ask participants about their perception of time pressure during the reading task. In the reading strategies questionnaire, participants were asked how attentive they were to the time when reading the text. While those in the high time pressure condition reported greater attentiveness to the time, thus providing some information about the impact of time pressure on navigation, specific questions about their perceptions of time pressure would have allowed us to obtain more information to relate to whether it affected their navigation and comprehension processes.

Another way of exerting time pressure could have been to include an on-screen countdown clock showing the remaining reading time. All participants in the digital text conditions could see the clock on the PC during the reading task, so they had some way to monitor their time. However, a countdown clock may have created the perception of time running out and therefore increased the amount of pressure participants felt. This would have been useful for increasing time pressure in conditions where the overall reading time was known. In the second experiment, high time pressure participants were not aware of the overall reading time and instead were told when they had five minutes remaining. This method may have only exerted high time pressure during these five minutes if participants were not concerned about running out of time prior to the prompt.

Alternatively, participants could have been told that they had less time in which to read the information (e.g., 15 minutes) than the estimated time to read all the text (e.g., 20 minutes). This may have increased feelings of time pressure by

making participants feel like they do not have enough time to access all the information and that they will therefore be more likely to underperform on the comprehension test. This method may have also impacted navigation behaviour; some participants may have chosen to not visit some pages, while others may have attempted to access all the information as quickly as possible in the given time. This would also shed some light on what readers perceive to be the most important information (which may be rehearsed, compared, and evaluated), and what they perceive to be less important (which may be scanned or intentionally ignored).

8.3 Learning from Hypertext: Role of Reading Comprehension and Individual Differences

The main focus throughout this thesis has been on how students learn from hypertext and how this differs to learning from other study media. Reading comprehension was used to assess learning because it relates to how readers understand the meaning of individual words, sentences, and texts as a whole (van den Broek et al., 2014). Furthermore, reading comprehension encompasses several passive and strategic processes that contribute to the formation of coherent mental representations of a text (Kintsch, 1988). These processes range from the automatic and minimally effortful (e.g., recognizing letters and words) to the deliberate and cognitively demanding (e.g., inferencing, creating semantic links between text parts and integrating prior knowledge; van den Broek et al., 2005). Having coherent representations of how the text is structured (surface structure), what the information means (propositional text base) and how it relates to what the reader already knows (situation model), is important because it allows the reader to better understand what is explicitly, and implicitly, conveyed by the text (Kintsch, 1988; Kintsch & van Dijk, 1978).

Working memory was identified as playing an important role in reading comprehension processes because it enables readers to encode, activate, store, and manipulate information (Baddeley, 2003). Individuals have different working memory capacities, as evidenced in studies showing that readers with high working memory capacity remember more information than those with low capacity (Baddeley, 1986; Daneman and Carpenter 1980; Lee-Sammons & Whitney, 1991). Daneman and Carpenter's (1980) seminal work described how readers maintain several propositions in working memory simultaneously to establish a cohesive mental representation of a text. The researchers showed, using the verbal span task, that process measures of working memory (e.g., encoding, updating) are differentially taxed by the processing demands of reading. If processing demands are high, then the limited stores of working memory can quickly become overburdened leading to weaker comprehension.

There are additional processing demands associated with digital text reading that are not found in print text reading (e.g., scrolling, clicking). Moreover, hypertext reading requires further processing due to the presence of hyperlinks and absence of linear structure (e.g., remembering where links are located, identifying connections between parts of the text). Previous research has described how these additional processing demands contribute to cognitive load and impact comprehension, especially in low working memory capacity readers (DeStefano & LeFevre, 2007). Because of their relevance to learning from texts, reading comprehension, and working memory, were assessed in each of the four experiments described in this thesis.

None of experiments in the present research included an independent measure of reading comprehension ability. Instead, they each assessed reading

comprehension performance (i.e., comprehension accuracy based on comprehension test results). Readers' ability to decode, integrate, and semantically process information has been found to independently predict reading comprehension in both children and adults (for a review, see, Landi, 2010). Given participants were at a similar academic level, it was assumed that they had similar overall reading comprehension ability. However, there may have been differences in comprehension skills between participants. A future experiment could assess reading comprehension ability and explore whether any differences in ability are related to comprehension and navigation across study media.

Overall, the present experiments found differences in students' comprehension scores across study media. In agreement with previous research, they found that print text learners had higher comprehension scores than digital text learners, including hypertext (Ackerman & Lauterman, 2012; Ackerman & Goldsmith, 2011; Baron, 2015; Clinton 2019; Delgado et al., 2018; Kong et al., 2018; Mangen et al., 2013; Noyes & Garland, 2008; Singer & Alexander, 2017; Ziefle, 1998).

The experiments differentiated between shallow (textual) and deep (inferential) reading comprehension by administering both multiple-choice answer test questions and short-answer questions. The distinction was made between these two levels of comprehension because learning involves more than the recollection of information; it involves inferential and deductive reasoning, critical analysis, reflection, and the ability to go beyond what is explicitly conveyed by the text (Wolf & Barzillai, 2009). Deep reading processes are integral to the formation of a coherent situation model in the C-I model (Kintsch, 1988; Kintsch & van Dijk, 1978). The C-I model considers many factors to be important for reading

comprehension, but suggests that prior knowledge, inferencing, and coherence are the most important for deeper comprehension.

Multiple-choice test questions were used in this thesis as a way of measuring shallow (textual) comprehension, requiring the reader to recall specific information. In contrast, the inferential comprehension items in the present research required the reader to integrate information located in different sections of the text, to form opinions based on what they had read, and to evaluate claims. Previous studies have used similar types of comprehension items to measure textual and inferential reading comprehension when comparing study media (e.g., Amadieu et al., 2017; Salmerón, et al., 2017).

An alternative approach to measuring reading comprehension would have been to instruct participants to write an essay or summary following the reading task, in which they would be required to demonstrate deep, inferential knowledge. Participants were aware that the comprehension test consisted of multiple questions, so may have read enough information to potentially answer a certain number of questions correctly. However, if preparing for an essay, they may have been more motivated to read all the text in order to have more information with which to complete the assessment.

The present research had mixed results for effect of study media on textual comprehension scores; one of the four experiments found that print text and scrolling text readers scored higher than hypertext readers, whereas three experiments found no effect of study media on textual comprehension scores. Previous reviews of studies on the effects of digital reading on textual comprehension have been similarly inconclusive (Dillon, 1992; Noyes & Garland, 2008; Singer & Alexander,

2017). In contrast, previous reviews have found more consistent results for the effect of study media on inferential comprehension. In agreement with this, the present research found weaker inferential comprehension of hypertext than of print text.

It is proposed that these results reflect that hypertext readers find it more challenging to engage in deep comprehension processes than print text readers do. This conclusion was also reached by recent reviews of digital and print text comparison studies (Clinton, 2019; Kong et al., 2018). A possible explanation for this is due to the Shallowing Hypothesis, which suggests that, because people are increasingly using digital media for quick interactions and receiving immediate rewards for those interactions (e.g., 'likes' and 'shares'), there are fewer opportunities to engage in sustained attention and deeper immersion online (Annisette & LaFreniere, 2017). The hypothesis follows that, consequently, individuals may find challenging online tasks (like deep reading comprehension in hypertext) more difficult to complete. This thesis has found that hypertext readers prioritise easier text and may miss other important information due to disorientation and navigational difficulties.

Interestingly, it was found that comprehension scores were also greater for scrolling text than hypertext. Moreover, comprehension of scrolling text was similar to print text comprehension, contrasting with studies that have found screen inferiority effects when comparing learning from print and digital texts (Ackerman & Goldsmith, 2011; Ben-Yehudah & Eshet-Alkalai, 2014; Daniel & Woody, 2013; Mangen et al., 2013). Many studies showing screen inferiority have attributed their findings to technological disadvantages (e.g., navigation difficulties) or to physical discomfort (e.g., eye strain). Others have suggested that learning in computerised

environments is associated with shallower cognitive processing, as evidenced by readers frequently reporting that they engage in sustained reading on paper but discontinuous reading on screen (Daniel & Woody, 2013; Liu, 2005). There is evidence that the equivalence between print and scrolling in the present research was because scrolling text has a familiar and explicit (i.e., linear) macrostructure that limits the need for readers to construct their own situation model, freeing up cognitive resources for deeper comprehension processes, like integration. For example, both print and scrolling text readers reported that they could find their way around the text, and were able to identify the beginning, middle, and end, more easily than hypertext readers. Moreover, both print text and scrolling text readers reported significantly less disorientation than hypertext readers.

Evidence of deep reading processes being inhibited by networked hypertext is that high prior knowledge readers demonstrated difficulties in integrating their prior knowledge. Typically, high knowledge readers perform better than those with low knowledge, and, while this effect was found for print text, it was not found for hypertext. Only after a graphical overview was introduced to provide an explicit structure and support navigation were high knowledge readers better able to integrate their prior knowledge and outperform low knowledge readers. This suggests that navigation plays an important role in how readers comprehend hypertext, and that differences between media in comprehension can be explained by difficulties in forming a coherent mental representation of text structure.

Conclusions about hypertext reading comprehension are framed within the context of the Cognitive Flexibility and Cognitive Load theories. On one hand, the Cognitive Flexibility Theory suggests hypertexts may be advantageous for learning, because the reader plays an active role in the reading process (Spiro et al., 1988).

According to this theory, learning in domains that are complex and lack a coherent structure takes place with continuous shifts between 'conceptual landscapes'; hypertext structures may increase opportunities for readers to use their existing knowledge in a flexible way to increase comprehension (Spiro et al., 1992; Spiro et al., 2012). On the other hand, hypertext reading involves multiple simultaneous activities including navigation, reading, integration of prior knowledge, inferencing, and updating (Sweller, 1988). The Cognitive Load Theory of reading comprehension suggests these processes contribute to an increase in cognitive load to the point where comprehension is affected.

It is proposed that the present research lends support to the Cognitive Load Theory. This is partly because it found that hypertext readers consistently reported navigation difficulties, were unable to integrate their prior knowledge, scored lower on the more cognitively demanding inferential comprehension test questions, and demonstrated (via log files) inefficient navigation behaviour. Moreover, the equivalence between print text and scrolling text suggests that differences between hypertext and print text are a result of the additional cognitive load in hypertext reading and the challenges of navigating a non-linear text structure. These findings challenge the Cognitive Flexibility Theory, which suggests that readers of different abilities are able to adapt to learning in ill-structured domains by spontaneously restructuring their knowledge and develop their own mental representations according to the situation (Spiro & Jehng, 1990). Given this assumption, it might have been expected that high prior knowledge readers would have been able to integrate their knowledge in hypertext. However, both low and high prior knowledge readers were disadvantaged when learning from hypertext, supporting the idea that hypertext greatly increases cognitive load and impairs performance.

This research found evidence that having greater ability to store and manipulate verbal and visuospatial information in working memory is important for comprehension, with visuospatial working memory being positively related to hypertext comprehension. The current results indicate that the orientation and layout of information is important for deeper comprehension, and that disadvantages of reading from hypertext are partly a result of navigational challenges and the absence of an explicit structure in hypertext. Evidence for this is that, in the fourth experiment which introduced a graphical overview, there was no longer a relationship between visuospatial working memory and hypertext comprehension scores, indicating that those with low visuospatial ability were no longer overburdened by the need to store information about where pages were located and the interconnections between pages because they were provided with this mental representation.

To conclude this section, this thesis successfully met its objective to assess reading comprehension across study media. It was found that hypertext readers had weaker inferential comprehension than print text readers. It is theorised that differences between print text and hypertext comprehension are a result of readers being unable to engage with deep comprehension processes and construct a mental representation of coherent text structure. Evidence for this is that networked hypertext readers had the lowest comprehension scores of all study media assessed in the present research. Networked hypertext had the most complex text structure, which is reflected in the fact that readers of this medium reported greater disorientation and greater difficulties identifying the beginning, middle, and end of the text. The added cognitive load of hyperlink selection and processing demands of

attempting to create a coherent mental representation of text structure may have led to weaker deep comprehension.

8.4 Navigating Hypertext

As previously described, the present experiments found that hypertext readers had weaker inferential comprehension than print text readers, and this was partly attributed to the consistently reported navigational difficulties and disorientation that they experienced. Graphical overviews were identified as a way of reducing disorientation in hypertext by facilitating navigation and the construction of a situation model. Providing hypertext readers with a graphical overview improved inferential comprehension scores in both low and high prior knowledge readers. Low prior knowledge readers were especially disadvantaged because they had two major challenges when learning from hypertext: navigational difficulties and not being able to integrate what they already knew to help bridge coherence gaps. It was also found that readers with a graphical overview engaged in more navigational behaviour considered beneficial for hypertext comprehension (e.g., spending greater time per page, making fewer clicks, fewer page revisits).

According to the Active Processing Model, highly structured overviews may inhibit readers' deep comprehension processes (e.g., inferencing and integrating prior knowledge) by limiting the need for discovering relations between sections, something which has been related to weaker comprehension (Hofman & van Oostendorp, 1999; Shapiro, 1998). Similarly, the Cognitive Flexibility Theory stresses the importance of learners having the opportunity to develop their own representations of information to improve comprehension (Spiro et al., 1989). An

overview may inhibit learners' adaptive response to changing situational demands and processes related to the construction of those representations.

However, the present results support an alternate explanation; graphical overviews provide an organisational framework which increases germane cognitive load, reduces extraneous cognitive load, and facilitates the navigation and comprehension of hypertext. This supports the view of the Assimilation Theory, which suggests that graphical overviews may enable readers to construct accurate mental representations, freeing up cognitive resources (that might otherwise have been used for building an accurate situation model) for deeper comprehension processes (Mayer, 1979; Salmerón et al., 2009). This is reflected in what the log files revealed about students' navigation of hypertext with an overview. Those without an overview visited more pages and spent a shorter average time on each page than those with an overview. This supports others' findings that readers go back and forth between hypertext pages more often when no clear text structure is available as they attempt to form coherence bridges between multiple sections (Blom et al., 2018).

However, it can only be inferred how hypertext readers spent their time navigating by looking at the information provided by the log files. A challenge throughout the present research has been how to make accurate assertions about hypertext readers' navigation behaviour with the log file information available, and how to relate this information to responses in the reading strategies questionnaires. Although the log files showed how long participants spent on each page, it could only be assumed that they were using that time to read and learn the text; they could have opened a page and not looked at the screen for several minutes. To minimise the risk that participants would not fully engage with the text, clear instructions to

participants were provided; they were instructed to read an informational text on which they would be tested afterwards.

One way of obtaining information about how hypertext readers used their time is to conduct think-aloud protocols in which readers verbalise their decision-making processes either before or after a reading task (Jääskeläinen, 2010). This may be useful when collecting additional information about why readers selected hyperlinks. However, participants who are asked to verbalise information that would not otherwise be attended to can be unreliable (Ericsson & Simon, 1980). While thoughts are widely considered to be sequential, individuals may not be able to accurately recall every sequence that led to a decision. Therefore, asking hypertext readers to verbalise their decision-making processes at every hyperlink selection may not be a reliable way of enriching log file information.

Another challenge to being able to make claims about the navigation of hypertexts in the present research is that there was a high number of unvisited pages in each of the experiments. The presence of a graphical overview reduced the number of unvisited pages, but in all other hypertext reading conditions, across all four experiments, there was a number of unvisited pages. Therefore, many participants did not read information that was necessary to correctly answer some of the comprehension items. In order to minimise the impact of unvisited pages on average measure calculations (e.g., average time spent per page), only the navigation of visited pages was analysed. Responses to all items of the comprehension test contributed to participants' comprehension scores, even if they did not visit a page where the information to correctly answer an item was located. This was done because participants were told that they would be tested after they had read the text. Tests in real life (e.g., academic tests) do not only assess information that students

have read. While some hypertext readers may not have visited all the pages, all participants had *access* to all information in the text.

There are several possible explanations for why pages were missed. One explanation is that participants were careless in their navigation activity; they had poor time-management and did not use appropriate strategies (e.g., connecting ideas, scanning for unread hyperlinks) for navigating hypertext. Another explanation is that readers made a strategic decision to visit a limited number of pages, because they thought they could acquire a sufficient amount of knowledge to answer most of the test questions correctly (when, in actuality, this resulted in weaker comprehension). The most likely explanation given all the findings, is that the missed pages reflected the difficulties that readers face when navigating hypertext, including not being able to easily locate new information.

To conclude this section, navigation has an important role in hypertext comprehension. This research has linked weaker reading comprehension performance to difficulties in navigating hypertext. According to Salmerón and colleagues (2016), good reading comprehension depends on a balanced trade-off between scanning and deeper processing. This research found support for this claim when assessing hypertext navigation. On one hand, while scanning was important for locating and selecting hyperlinks, if readers spent too much time doing this, they sacrificed opportunities to engage in deeper comprehension processes (e.g., making inferences and bridging coherence gaps). This was reflected in weaker inferential comprehension scores. On the other hand, activities like spending longer on pages were important for gaining deeper comprehension, but too much time doing these activities meant that hyperlinks and entire pages were missed due to the absence of familiarisation periods to find out where information was located. This resulted in

lower overall comprehension scores. In addition, the results found support for graphical overviews as a means to facilitate the navigation of hypertexts. It is suggested they do this by increasing germane load, lowering extraneous load, and by providing an explicit structure to free up cognitive resources for engaging in processes that contribute to deeper text comprehension.

8.5 Revisiting Measures

This section will consider some evaluation points for each of the main measures used throughout the four experiments, including why they were selected and how they contributed to the research aims. While each of the four empirical chapters have their own detailed discussion sections (Chapters 4-7), this section will consider some of general strengths and limitations of the measures throughout the thesis.

Comprehension. Because the texts used in the four experiments were new (i.e., constructed from multiple sources to form new texts), it was necessary to also design the comprehension questionnaires that assessed the learning from those texts. The comprehension items were constructed so that they fit the definition of textual and inferential comprehension. This allowed for the measurement of both shallow and deep comprehension. As with any questionnaire with multiple response items, participants may have answered correctly by guessing. However, participants generally scored higher than chance (25%), and there was a wide range of scores in each experiment. The comprehension test used in the first two experiments was improved upon in subsequent experiments by including the same number of inferential and textual questions.

A potential limitation of the comprehension measure is that some integration items may have instead measured textual comprehension. For example, short-answer questions that required participants to compare two pieces of information located in different sections of the text may have activated shallow retrieval processes rather than the targeted deeper evaluation processes. However, expected differences between textual and integration comprehension were found, lending support to these items assessing different levels of comprehension. The integration comprehension items could be improved in future experiments by being more essay-based, requiring participants to think more deeply, and for longer, about how the information fits with what they already know and whether inferences can be made beyond what is explicitly mentioned. An alternative experimental design would have been to administer the comprehension test again in the days or weeks following the reading task. This would have assessed how much textual or integration comprehension was committed to long-term memory, and whether there were any differences between study media.

Working Memory. It was identified that hypertext readers may need high cognitive flexibility; hyperlinks frequently disrupt central executive processes by requiring additional decision-making at each link (e.g., whether to click immediately or not). Therefore, switching ability may be important when learning from hypertext because readers may need to alternate between deep processing (e.g., reading a sentence and making inferences) and shallow processing (e.g., identifying meaning of hyperlinked word embedded in a sentence). One way of measuring these central-executive measures is by using the trail-making test from the Delis-Kaplan Executive Function System (DKEFS; Delis, Kaplan, & Kramer, 2001). In the first two experiments, it was found that switching ability was not related to

comprehension across study media. This measure was dropped for the subsequent two experiments because there was no relation between this and the other measures, including navigation and comprehension.

A possible explanation for these results is that the trail-making test may not have been the most suitable way of measuring switching ability for these experiments. The task involves quickly drawing a line between numbers and letters, whereas the kind of switching in hypertext reading involves switching between concepts or ideas, and alternating between types of processing. Therefore, an alternative executive function test such as the Wisconsin Card Sorting Test (WCST; Delis et al., 2001; Heaton et al., 1993), which has been shown to independently tap switching and inhibitory control (e.g., Miyake et al., 2000), may be more relevant in this context. In the WSCT, participants discover how to sort a deck of cards, which may relate to how readers discover relations between webpages in hypertext.

In each of the four experiments, a verbal test was used as a measure of verbal working memory. This was adapted from the verbal component of Wechsler Adult Intelligence Scale (WAIS), which is a valid measure of a person's ability to attend to information presented verbally, manipulate that information in short-term immediate memory, and then formulate a response (for reviews, see, Hill et al., 2010; Lange, 2011). The WAIS requires participants to recall digits, and this task was adapted so that participants had to recall and manipulate the sequence of words. The rationale behind this was that hypertext reading involves the recollection of individual hyperlinked words; readers remember what the hyperlinked word is, its location, and how it relates to other information. The current results found that verbal working memory was not related to comprehension of hypertext. This measure was retained throughout the research because conflicting findings in the relevant research

literature about the effect of verbal working memory on comprehension across study media were identified.

In addition, all four experiments used the spatial span subtest of the Wechsler Non-Verbal Scales of Ability as a measure of visuospatial working memory (Wechsler & Naglieri, 2006). It was identified that hypertext reading involves recalling where information is located in hyperspace. Readers must then reorganise that information to help construct a mental representation of text structure that is coherent and can be easily recalled when making navigation decisions. In contrast, print text reading involves the navigation of a more explicit structure which requires less manipulation of visuospatial information to maintain coherence. Therefore, it was expected that hypertext readers would benefit from greater visuospatial working memory capacity. The results agreed with previous findings that visuospatial working memory is positively related to comprehension of hypertext.

A limitation of the working memory tests used throughout this thesis is that they took up a large portion of the total testing time to complete, potentially creating the perception in some participants that the main purpose of the experiment was about memory instead of comprehension. Moreover, while participants commented on the novelty of tasks, they also indicated that they felt pressured by the 1:1 testing administered by the experimenter. An alternative approach to measuring verbal and visuospatial working memory would be to use computerised tests. Ma et al. (2017) developed a battery of computerised working memory tests (measuring visuospatial sketchpad, phonological loop, inhibition and switching) suitable for young adults, finding that they were less time-consuming while they also collected more data than traditional offline tests. This may have helped participants feel less pressured going into the reading task, and encouraged them to think more about comprehension (i.e.,

deep learning) than memory (e.g., basic recall). To minimise the risk that participants were thinking more about recall than comprehension in the current research, the working memory tasks could have been administered after the reading task.

Metacognition. The first two experiments included metacognitive questionnaires which asked participants to rate pre-test and post-test confidence in each of the comprehension items. These measures were dropped in the subsequent two experiments. One reason for this is that the single overall comprehension score prediction measure revealed more about participants' confidence in their responses. Moreover, there were concerns about questionnaire fatigue and potential participant response apathy by the third experiment; feedback from some participants in the first two experiments was that they were bored by the end of the questionnaires proceeding the reading task (which took about 30 minutes to complete). This is reflected in the fact that there were many percentage responses in the region of 50% on the metacognitive questionnaire; frequent mid-point questionnaire responses are considered an indication of ambivalent participants (Baka et al., 2012). Previous research has found that positive affect participants show larger confidence than neutral affect participants (Sidi et al., 2018). Therefore, if participants had larger negative affect (e.g., disinterest, low engagement), they may have been more likely to show underconfidence. Dropping these questionnaires (which were longer and more repetitive than other measures) reduced the amount of negative feedback from participants.

'PIE' Questionnaires. A questionnaire was designed to measure participants' comprehension score predictions, topic interest, and engagement (PIE). Two versions of this questionnaire were administered: a pre-test version (before the

reading task), and a post-test version (after the reading task and comprehension test). These questionnaires provided a wealth of information which could be related to the other measures. This questionnaire was improved in the third and fourth experiments by the addition of items including, 'Considering the medium (i.e., hypertext, print text), how difficult did you find it to learn from?' These items allowed for further comparisons between study media. For example, it was found that participants reported a strong preference for print text, and that hypertext participants predicted that they would have performed better on the comprehension test if they had been in the print text condition.

A potential limitation of the PIE questionnaire is that in the first two experiments, the measure of mental effort was poorly defined. The question, 'How much effort do you think will be required to answer the test questions correctly', was intended to measure the overall effort required to learn the information. However, this could have been interpreted as asking how difficult participants found the test questions. The mental effort measure in this thesis was improved upon in the subsequent two experiments, by asking participants more specific questions about how difficult they thought the test questions would be, how difficult they predicted the content would be to learn, and how difficult they predicted the medium would be to learn from. Another limitation is that subjective appraisals of effort may be subject to bias, as suggested by a recent review of mental effort assessments in metacognitive research (Schieter et al., 2020). A more general criticism of the PIE questionnaire is that it offered no information that could be compared to participants' reading strategies or navigation behaviour. This could be improved in future experiments by asking participants to predict what strategies they may have to employ during the reading task, and to predict how they intend to navigate hypertext.

This could then be compared to the strategies they actually employed, and how they actually navigated.

Navigation. The primary measure of hypertext navigation was log file data. Consistent with others' use of log files to assess navigation of hypertext (e.g., Blom et al., 2018), the experiments measured how long participants spent per page, their link selection, and the order in which they accessed the text. Moreover, the navigation behaviour of readers of the highest and lowest comprehension scores were explored to identify common dis/advantageous behaviour for navigation and learning. Using this method, similar findings to earlier research were identified (Hahnel et al, 2016; Lawless & Kulikowich, 1996). Namely, that spending longer on pages is related to deeper comprehension, whereas scanning is related to shallower comprehension.

A potential limitation of this method is that participants may have suspected that their navigation was being monitored, so adapted their behaviour according to demand characteristics. Although this was a possibility, participants were not told that their navigation would be recorded, and the task instructions informed them that the focus of the experiment was about learning rather than navigation. Therefore, the likelihood that participants suspected their navigation was being recorded was low. Another potential limitation of this navigation method is that participants were left to read the text on their own (in an individual PC booth away from the researcher). A consequence of this may have been that participants clicked through the text to 'pass the time' rather than actually read it. However, the navigation results indicated that this possibility was low; there was a range of reading times in each of the conditions, and there were no anomalously low reading comprehension scores. An alternative approach would have been to either have the experimenter in

the same room as the participants, or to film participants as they completed the reading task, in order to be sure how they were using the reading time.

Reading Strategies. Information about readers' navigation behaviour (provided by log files) was sought to be enriched by including a measure of their self-reported reading strategies. It was hoped that learning about what strategies participants employed would help explain why particular navigation decisions were made. In the first two experiments, an existing reading strategies questionnaire was developed by selecting items from it that asked readers about their activities during the reading task (e.g., 'Now and then I stopped reading to think through what I had read'). However, this required a lot of inferencing to make connections between the responses and the log file information. For example, it was inferred that responses to the item, 'Now and then I stopped reading to think through or repeat what I had read', would be related to longer time spent per page, and greater comprehension scores. However, this may not have been an accurate reflection of how participants used their time on each page, and there were no correlations between any of the items and log file information.

The reading strategies questionnaire was improved in the third and fourth experiments by the inclusion of items that could more easily (and accurately) be related to the log file information. For instance, the multiple-choice item, 'When I encountered a page with more than one hyperlink…' had options including, 'I clicked on the first one', and, 'I clicked on the second one'. This allowed for participants' navigation to be explored to see whether they did click on the first hyperlink or not. It was found that participants were accurate in how they reported their navigation, and that some of these new reading strategies items were correlated to log file measures. For example, there was a positive relationship between greater

use of the strategy, 'I made sure to go back and click on hyperlinks I missed during the first page visit', and visits per page. While this approach provided a wealth of reading strategies data, a limitation was that there were considerable time demands of analysing log files and relating navigation to participant reports of their navigation. Therefore, future research could explore ways of further automating the analysis of log files.

The reading strategies questionnaire could be improved in future experiments by having a pre-test and post-test version. A pre-test questionnaire might ask participants about any strategies they have previously learned (e.g., scanning before reading), in addition to how they plan to approach the current reading task. A post-test version might ask about whether they were successful in employing these strategies and if they had to adapt their approach given the task conditions (e.g., reading time constraints, text medium). This would provide more information to either support or challenge the claim made by the Cognitive Flexibility Theory that readers are highly adaptable to the reading situation. Alternatively, short interviews could be conducted following the reading task to obtain detailed information about which strategies readers implemented, including those they did not use (i.e., if they thought they would not contribute positively to the reading goal).

8.6 Contributions and Potential Beneficiaries

This thesis has contributed to the 'Screen versus Paper' debate. According to Noyes and Garland (2008), while equivalence between computer and paper-based tasks is impossible, the importance of any differences is specific to the task. The present research found evidence of several advantages of print text over hypertext. However, it also found evidence of equivalence between print text and a type of

digital text for learning (i.e., scrolling text). Therefore, this research supports the claim that differences between screen and paper learning depends on the reading task, the reading goal, text type, and other factors including individual differences.

This research may be of benefit to educators, as it has shown that students with low prior knowledge may be especially disadvantaged when learning from hypertext, so educators should be cautious when asking their students to develop deep comprehension via hypertext when the topic is new. Instead, educators should use all the learning resources at their disposal to enable students to learn effectively during a variety of reading tasks. For example, they might promote print text resources when deep comprehension of a new topic is required, or encourage online reading when basic information needs to be located quickly. When print text resources are no longer an option (due to the complete integration of e-books as a replacement for textbooks), educators might suggest reading activities which facilitate deep learning in digital text, like familiarisation and review periods (Bolaños, 2012), or they might promote digital reading alternatives to hypertext such as scrolling text.

In agreement with the findings of others' research into students' study preferences, participants in the present research overwhelmingly reported a strong preference for reading and learning from print text over digital text. Metacognition may be at the heart of the explanation for this; hypertext readers may be aware that they are not processing information as deeply as in print text so do not learn as well in online contexts. This is supported by consistent feedback from participants that they generally 'find it difficult to learn' from screen texts. Therefore, this research may also be of interest to web designers, who may wish to improve the online reading experience. For example, if it was common for hypertexts to include

graphical overviews, over time hypertext readers may become accustomed to using an overview to identify structure, facilitate navigation and comprehension, and reduce disorientation. As a result, this may improve familiarisation with hypertext structure to equal that of print texts. Future technological advancements may lead to further adaptive hypertext systems which guide navigation towards goal-relevant information. Such as system would depend on the reading goal; in some situations, readers may be content to explore hypertext to discover new information without the need for prompts of where to orient their attention.

Discovering new and interesting information is part of the joy of reading. However, in situations where readers want to access related information in as few 'clicks' as possible, a hypertext feature which guides readers to relevant information may be very useful. The reading goal (e.g., discovery versus locating) the reader (e.g., prior knowledge), the text (e.g., informational or narrative) and text medium (e.g., print versus digital) are all relevant factors to consider when developing ways to improve navigation and comprehension.

8.7 Future Directions

Although hypertext research has taken place for nearly three decades (for reviews, see Delgado et al., 2018; DeStefano & LeFevre, 2007; Dillon et al., 1990; Pang, 1998), there remains a need for research exploring how readers navigate and learn from hypertext. There exist disadvantages of learning from digital texts over print texts, and recent findings that the gap between print and digital text learning is increasing highlights the necessity for up-to-date research investigating how to

mitigate this. This research has revealed some of the ways in which navigation and learning differs across study media. However, some findings may wish to be investigated further.

For example, two of the present experiments introduced a familiarity questionnaire which asked participants how often during a typical week they spend reading print texts, online texts, and hypertexts for leisure and for learning purposes. In agreement with previous findings, it was predicted that familiarity with the study media would be positively related to comprehension of that media (Chen et al., 2014; Lee & Tedder 2003). Instead, correlational analyses found that, for print text participants, a greater amount of time spent reading online was positively related to comprehension. For hypertext participants, a greater amount of time spent reading print text positively related to comprehension. A possible explanation is that readers were able to draw upon skills from print and hypertext reading which benefitted them when learning from an alternative medium. Alternatively, there may have been a novelty effect of reading from an unfamiliar medium, meaning readers recruited extra mental effort in order to improve comprehension. The relative impact of study media experience and preference on comprehension may be of interest to future investigators.

One factor the present research did not assess is reading skill. Reading skills are distinguished from reading strategies, which are conscious and intentional processes (Alexander et al., 1998). Leu and colleagues' (2004) 'independent model' proposed that reading skills and navigation are not related, and instead have an independent impact on comprehension, evidence for which was found in a study of seventh-grade students (Leu et al., 2005). In contrast, Naumann and colleagues (2008) proposed a mediation model in a study with undergraduate students, in which

reading skills such as word recognition and semantic integration have an independent positive effect on the quality of navigation behaviour (e.g., selecting task-relevant pages), which in turn has a positive impact on reading comprehension performance. Alternatively, Salmerón and García's (2011) study examined the hypertext navigation strategies of sixth graders, suggesting a side-effect model in which navigation strategies do not have an independent impact on comprehension because they are a side effect of reading skills.

Therefore, examining students' reading skills may help researchers to understand why they choose to implement some navigation strategies and why they do not implement other strategies. In the present research, all participants were assumed to have a similar reading ability because of their academic level. Both reading skills and navigation strategies may be of interest to future researchers exploring the navigation and comprehension of hypertext, particularly in children whose reading skills are still developing.

As previously mentioned, the reading purpose is important to consider when assessing how readers engage with texts. While the present experiments provided participants with clear instructions on what would be required of them during the study, they were not explicitly told to gain a deep comprehension of the text. It was presumed that in learning contexts participants would want to learn the information deeply, but this is not always the case. Sometimes readers may wish to gain a 'functional' comprehension of a text in order to achieve a pass grade on a test rather than complete mastery, or they may adopt lower standards of coherence meaning they choose not to engage in more deep comprehension processes (van den Broek, 1999). It would be interesting to assess navigation and comprehension across study

media in highly motivated participants who are instructed to gain a deep comprehension of a text.

8.8 Concluding Remarks

The Covid-19 pandemic of 2020 has highlighted the necessity of online information in modern society. During this period vital healthcare information has been distributed on government and health service websites, students have accessed learning materials online and attended virtual classrooms, numerous business have begun operating entirely remotely, and communication with friends and family has largely taken place though social media platforms. Reading textual information on screens is the new normal, and this is generally a good thing. The main motivation of this thesis was not to highlight disadvantages of digital texts, but to explore the ways in which they differ from print texts. In doing so, it identified some additional challenges of navigating and learning from hypertext that are not present in traditional print text reading. However, it has also shown that, with novel hypermedia features, these might be overcome. Whether reading takes place on print or screen, we should be thankful that we live in a world with a multitude of reading options to suit a range of learning goals and preferences.

Bibliography

Abbasi, I. S., & Alghamdi, N. G. (2015). The prevalence, predictors, causes, treatments, and implications of procrastination behaviors in general, academic, and work setting. *International Journal of Psychological Studies, 7*(1), 59-66.

Ackerman, R., & Beller, Y. (2017). Shared and distinct cue utilization for metacognitive judgments during reasoning and memorisation. *Thinking and Reasoning, 23(4),* 376-408.

Ackerman, R., & Goldsmith, M. (2011). Metacognitive regulation of text learning: on screen versus on paper. *Journal of Experimental Psychology: Applied, 17*(1), 18-32. https://doi.org/10.1037/a0022086

Ackerman, R., & Lauterman, T. (2012). Taking reading comprehension exams on screen or on paper? A metacognitive analysis of learning texts under time pressure. *Computers in Human Behavior, 28*(5), 1816-1828.

Ackerman, R., & Thompson, V. A. (2017). Meta-Reasoning: Monitoring and control of thinking and reasoning. *Trends in Cognitive Sciences, 21*(8), 607-617.

Ahuja, J., & Webster, J. (2001) Perceived disorientation: An examination of a new measure to assess web design effectiveness. *Interacting with Computers, 14*, 15-29.

Akbar, R., Al-Hashemi, A., Taqi, H., & Sadeq, T. (2013). Efficacy of learning: Digital sources versus print. *Journal of Education and Practice, 4*(8), 98-114.

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proWciency. *Educational Researcher, 32*(8), 10-14.

Alexander, P. A., & Jetton, T. L. (2000). Learning from text: A multidimensional and developmental perspective. *Handbook of Reading Research, 3*, 285-310.

Ali, A. Z. M., Wahid, R., Samsudin, K., & Idris, M. Z. (2013). Reading on the computer screen: Does font type has effects on web text readability? *International Education Studies, 6*(3), 26-35.

Al-Sulaimi, A., & Al-Shihi, H. (2018). The effects of reading mode (digital vs printed text) on reading comprehension: A literature review of the key assessment factors. In *2017 6th International Conference on Information and Communication Technology and Accessibility, ICTA 2017* (Vol. 2017-December, pp. 1–6). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICTA.2017.8336053

Alter, A. L., Oppenheimer, D. M., Epley, N., & Eyre, R. N. (2007). Overcoming intuition: metacognitive difficulty activates analytic reasoning. *Journal of Experimental Psychology: General, 136*, 569-576.

Amadieu, F., Lemarié, J., & Tricot, A. (2017). How may multimedia and hypertext documents support deep processing for learning?. *Psychologie Française, 62*(3), 209-221.

Amadieu, F., Salmerón, L., Cegarra, J., Paubel, P. V., Lemarié, J., & Chevalier, A. (2015). Learning from concept mapping and hypertext: An eye tracking study. *Journal of Educational Technology & Society, 18*(4), 100-112.

Amadieu, F., Tricot, A., & Mariné, C. (2009). Prior knowledge in learning from a non-linear electronic document: Disorientation and coherence of the reading sequences. *Computers in Human Behavior, 25*(2), 381-388.

Amadieu, F., Tricot, A., & Mariné, C. (2010). Interaction between prior knowledge and concept-map structure on hypertext comprehension, coherence of reading orders and disorientation. *Interacting with Computers, 22*, 88–97.

Amadieu, F., Tricot, A., & Mariné, C. (2011). Comprendre des documents non-linéaires: quelles ressources apportées par les connaissances antérieures?. *L'Année Psychologique*, *111*(2), 359-408.

Amadieu, F., Van Gog, T., Paas, F., Tricot, A., & Mariné, C. (2009). Effects of prior knowledge and concept-map structure on disorientation, cognitive load, and learning. *Learning and Instruction, 19,* 376-386. https://doi.org/10.1016/j.learninginstruc.2009.02.005

Anmarkrud, Ø., Andresen, A., & Bråten, I. (2019). Cognitive load and working memory in multimedia learning: Conceptual and measurement issues. *Educational Psychologist*, *54*(2), 61-83.

Anmarkrud, O., & Braten. I. (2009). Motivation for reading comprehension. *Learning and Individual Differences, 19*, 252-256.

Annisette, L. E., & Lafreniere, K. D. (2017). Social media, texting, and personality: A test of the shallowing hypothesis. *Personality and Individual Differences, 115*, 154-158. https://doi.org/10.1016/j.paid.2016.02.043

Antonenko, P. D., & Niederhauser, D. S. (2010). The influence of leads on cognitive load and learning in a hypertext environment. *Computers in Human Behavior, 26*(2), 140-150.

Azevedo, R., Moos, D. C., Greene, J. A., Winters, F. I., & Cromley, J. G. (2008). Why is externally-facilitated regulated learning more effective than self-regulated

learning with hypermedia?. *Educational Technology Research and Development*, *56*, 45-72.

Baadte, C., & Dutke, S. (2013). Learning about persons: the effects of text structure and executive capacity on conceptual change. *European Journal of Psychology of Education*, *28*(3), 1045-1064.

Baddeley, A. D. (1986). *Working memory*. Clarendon Press.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Science, 4*, 417-423. https://doi.org/10.1016/ S1364-6613(00)01538-2

Baddeley, A. D. (2001). Is working memory still working? *The American Psychologist, 56*, 851-864. https://doi.org/10.1037/0003-066X.56.11.851

Baddeley, A. D. (2003). Working memory and language: an overview. *Journal of Communication Disorders, 36(3)*, 189-208.

Baddeley, A. D. (2007). Working memory: Multiple models, multiple mechanisms. In H. L. Roediger, Y. Dudai, & S. M. Fitzpatrick (Eds.), *Science of memory: Concepts* (pp. 151-153). Oxford University Press.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *Recent advances of learning and motivation* (pp. 47-89). Academic Press.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: the multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28-61). Cambridge University Press.

Baka, A., Figgou, L., & Triga, V. (2012). “Neither agree, nor disagree”: A critical analysis of the middle answer category in Voting Advice Applications. *International Journal of Electronic Governance, 5*(3), 244-263.

Barab, S. A., Bowdish, B. E.,&Lawless, K. A. (1997). Hypermedia navigation: Profiles of hypermedia users. *Educational Technology Research and Development, 45*, 23-42.

Baron, N. S. (2017). Reading in a digital age. *Phi Delta Kappan*, *99*(2), 15-20.

Barron, P. (2011). E-Readers in the Classroom. *Transformations: The Journal of Inclusive Scholarship and Pedagogy*, *22*(1), 133-138.

Barthakur, R (2013). Computer Vision Syndrome. *Internet Journal of Medical Update, 8*(2), 1–2.

Barzillai, M., Thomson, J., van den Broek, P., & Schroeder, S. (Eds). (2018*). Learning to read in a digital world*. John Benjamins.

Basaraba, D., Yovanoff, P., Alonzo, J., & Tindal, G. (2013). Examining the structure of reading comprehension: do literal, inferential, and evaluative comprehension truly exist?. *Reading and Writing*, *26*(3), 349-379.

Bayazit, A., Bayram, S., & Cumaoglu, G. K. (2018). Investigating the Relationship between Task Complexity, Cognitive Ability and Disorientation in Hypertext Navigation. *World Journal on Educational Technology: Current Issues*, *10*(4), 115-127.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M., & Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology*, *41*(4), 579-597.

Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The complexities of complex span: explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General*, *132*(1), 71-92.

Bezdan, E., Kester, L., & Kirschner, P. A. (2013). The influence of node sequence and extraneous load induced by graphical overviews on hypertext learning. *Computers in Human Behavior, 29*(3), 870-880.

Bird, K. D., & Hadzi-Pavlovic, D. (2014). Controlling the maximum familywise Type I error rate in analyses of multivariate experiments. *Psychological Methods*, *19*(2), 265-281.

Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe & A. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 185–205). MIT Press.

Blom, H., Segers, E., Knoors, H., Hermans, D., & Verhoeven, L. (2018). Comprehension and navigation of networked hypertexts. *Journal of Computer Assisted Learning*, *34*, 306-314.

Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition, 104*, 198-230. https://doi.org/10.1016/j.cognition.2006.05.009

Bowyer-Crane, C., & Snowling, M. J. (2005). Assessing children's inference generation: What do tests of reading comprehension measure? *British Journal of Educational Psychology, 75*(2), 189-201. https://doi.org/10.1348/000709904X22674

Britt, M. A., Rouet, J. F., & Durik, A. M. (2017). *Literacy beyond text comprehension: A theory of purposeful reading*. Routledge.

Britt, M. A., Rouet, J.-F., & Perfetti, C. A. (1996). Using hypertext to study and reason about historical evidence. In J.-F. Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), *Hypertext and cognition* (pp. 43-72). Lawrence Erlbaum Associates, Inc.

Broadbent, D. (1958). *Perception and communication.* Pergamon Press.

Brown, A. L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65-116). Lawrence Erlbaum Associates.

Burin, D. I., Barreyro, J. P., Saux, G., & Irrazábal, N. C. (2015). Navigation and comprehension of digital expository texts: Hypertext structure, previous domain knowledge, and working memory capacity. *Electronic Journal of Research in Educational Psychology, 13*(3), 529-550. https://doi.org/10.14204/ejrep.37.14136

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology, 96*(1), 31-42. https://doi.org/10.1037/0022-0663.96.1.31

Calisir, F., Eryazici, M., & Lehto, M. R. (2008). The effects of text structure and prior knowledge of the learner on computer-based learning. *Computers in Human Behavior*, *24*, 439-450.

Calisir, F., & Gurel, Z. (2003). Influence of text structure and prior knowledge of the learner on reading comprehension, browsing and perceived control. *Computers in Human Behavior, 19*(2), 135-145.

Cangoz, B., & Altun, A. (2012). The effects of hypertext structure, presentation and instruction types on perceived disorientation and recall performances. *Contemporary Educational Technology*, *3*(2), 81-98.

Cantin, R. H., Gnaedinger, E. K., Gallaway, K. C., Hesson-McInnis, M. S., & Hund, A. M. (2016). Executive functions predict reading, mathematics, and theory of mind during the elementary years. *Journal of Experimental Child Psychology, 146*, 66–78. https://doi.org/10.1016/ j.jecp.2016.01.014

Cartelli, A. (Ed.). (2012). *Current trends and future practices for digital literacy and competence*. IGI Global.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293-332.

Charney, D. (1987). Comprehending non-linear text: The role of discourse cues and reading strategies. *Proceedings of the ACM conference on Hypertext*, 109-120.

Chen, C. M., & Lin, Y. J. (2016). Effects of different text display types on reading comprehension, sustained attention and cognitive load in mobile reading contexts. *Interactive Learning Environments*, *24*(3), 553-571.

Chen, S. Y., & Macredie, R. (2010). Web-based interaction: A review of three important human factors. *International Journal of Information Management, 30*, 379–387.

Cho, B-Y. (2014). Competent adolescent readers' use of Internet reading strategies: A think-aloud study. *Cognition and Instruction, 32*, 252–289. doi:10.1080/07370008.2014.918133

Chuderski, A. (2013). When are fluid intelligence and working memory isomorphic and when are they not?. *Intelligence, 41*(4), 244-262.

Chuderski, A. (2016). Time pressure prevents relational learning. *Learning and Individual Differences*, *49*, 361-365.

Clark, C., & Teravainen-Goff, A. (2020). *Children and Young People's Reading in 2019: Findings from our Annual Literacy Survey*. National Literacy Trust.

ClickTale. (2006, August 13). *Unfolding the fold*. Clicktale. http://blog.clicktale.com/2006/12/23/unfolding-the-fold/

Clinton, V., & Van den Broek, P. (2012). Interest, inferences, and learning from texts. *Learning and Individual Differences*, *22*(6), 650-663.

Clinton, V. (2019). Reading from paper compared to screens: A systematic review and meta-analysis. *Journal of Research in Reading*, *42*(2), 288–325. https://doi.org/10.1111/1467-9817.12269.

Coiro, J., Castek, J., & Guzniczak, E. (2011). Uncovering online reading comprehension processes: two adolescents reading independently and collaboratively on the Internet. *Yearbook of the Literacy Research Association, 60*, 354-369.

Conklin, J. (1987). Hypertext: an introduction and survey. *Computer, 9*, 17-41.

Conradty, C., & Bogner, F. (2016). Hypertext or textbook: Effects on motivation and gain in knowledge. *Education Sciences, 6*(1), 29-44. https://doi.org/10.3390/educsci6030029

Corcoran, B. (2014, July 23). *Blackboard's Jay Bhatt strikes up the brass band*. EdSurge. https://www.edsurge.com/news/2014-07-23-blackboard-s-jay-bhatt-strikes-up-the-brass-band

Courage, M. L. (2017). Screen media and the youngest viewers: Implications for attention and learning. In F. C. Blumberg & P. J. Brooks (Eds.), *Cognitive development in digital contexts* (pp. 3-28). Academic Press.

Cress, U., & Knabel, O. B. (2003). Previews in hypertexts: effects on navigation and knowledge acquisition. *Journal of Computer Assisted Learning*, *19*(4), 517-527.

Dalton, B., & Proctor, C. (2008). The changing landscape of text and comprehension in the age of new literacies. In: J. Coiro, M. Knobel, C. Lankshear, & D. Leu (Eds.). *Handbook of research on new literacies* (pp. 297–324). Routledge.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466.

Davis, D. S., & Neitzel, C. (2012). Collaborative sense-making in print and digital text environments. *Reading and Writing, 25*, 831–856.

DeDonno, M. A., & Demaree, H. A. (2008). Perceived time pressure and the Iowa Gambling Task. *Judgment and Decision Making*, *3*(8), 636-640.

Dee-Lucas, D. (2012). Effects of overview structure on study strategies and text representations for instructional hypertext. In Rouet, J. J. Levonen, A. Dillon,

& R. J. Spiro (Eds.), *Hypertext and cognition* (pp. 83–118). Lawrence Erlbaum Associates, Inc.

Dehn, M. J. (2011). *Working memory and academic learning: Assessment and intervention*. John Wiley & Sons.

Delgado, P., Vargas, C., Ackerman, R., & Salmerón, L. (2018). Don't throw away your printed books: A meta-analysis on the effects of reading media on reading comprehension. *Educational Research Review*, *25*, 23-38.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis Kaplan Executive Function System: Examiner's manual*. Psychological Corporation.

DeStefano, D., & LeFevre, J. A. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior*, *23*(3), 1616-1641.

Dias, P., & Sousa, P. A. (1997). Understanding navigation and disorientation in hypermedia learning environments. *Journal of Educational Multimedia and Hypermedia*, *6*, 173–185.

Dilevko, J., Gottlieb, L. (2002). Print sources in an electronic age: A vital part of the research process for undergraduate students. *The Journal of Academic Librarianship, 28,* 381–392.

Dillon, A., Richardson, J., & McKnight, C. (1990). Navigation in hypertext: a critical review of the concept. In D. Diaper, D. Gilmore, G. Cockton, & B. Shackel (Eds.), *INTERACT '90* (pp. 587-592). North Holland.

Dobler, E. (2015). e-Textbooks: A Personalized Learning Experience or a Digital Distraction?. *Journal of Adolescent & Adult Literacy*, *58*(6), 482-491.

Downing, R. E., Moore, J. L., & Brown, S. W. (2005). The effects and interaction of spatial visualization and domain expertise on information seeking. *Computers in Human Behavior, 21*(2), 195-209.

Duncan, L. G., McGeown, S. P., Griffiths, Y. M., Stothard, S. E., & Dobai, A. (2015). Adolescent reading skill and engagement with digital and traditional literacies as predictors of reading comprehension. *British Journal of Psychology, 107*, 209–238. https://doi.org/10.1111/bjop.12134

Dunlosky, J., & Nelson, T. O. (1992). Importance of the kind of cue for judgments of learning (JOL) and the delayed-JOL effect. *Memory & Cognition, 20*, 374-380.

Dunlosky, J., & Thiede, K. W. (1998). What makes people study more? An evaluation of factors that affect self-paced study. *Acta Psychologica, 98*(1), 37-56.

Durant, D. M., & Horava, T. (2015). The future of reading and academic libraries. *Portal: Libraries and the Academy, 15*(1), 5-27.

Dyson, M. C. (2004). How physical text layout affects reading from screen. *Behaviour & Information Technology, 23*(6), 377-393.

Dyson, M., & Haselgrove, M. (2000). The effects of reading speed and reading patterns on the understanding of text read from screen. *Journal of Research in Reading*, *23*(2), 210-223.

Eastin, M. S., Yang, M. S., & Nathanson, A. I. (2006). Children of the net: An empirical exploration into the evaluation of Internet content. *Journal of Broadcasting & Electronic Media, 50*(2), 211-230.

Elleman, A. M. (2017). Examining the impact of inference instruction on the literal and inferential comprehension of skilled and less skilled readers: A meta-

analytic review. *Journal of Educational Psychology*, *109*(6), 761–781. https://doi.org/10.1037/edu0000180

Engle, R. W. (2018). Working memory and executive attention: A revisit. *Perspectives on Psychological Science*, *13*(2), 190-193.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, *87*(3), 215-251. https://doi.org/10.1037/0033-295X.87.3.215

Ericsson, K. A., & Simon, H. A. (1993). Protocol analysis: Verbal reports as data. MIT Press.

Fesel, S. S., Segers, E., de Leeuw, L., & Verhoeven, L. (2016). Strategy training and mind-mapping facilitates children's hypertext comprehension. *Written Language & Literacy*, *19*(2), 131-156.

Fitzsimmons, G. (2017). *The influence of hyperlinks on reading on the web: an empirical approach* [Unpublished doctoral dissertation]. University of Southampton.

Fitzsimmons, G., Weal, M. J., & Drieghe, D. (2016). Reading, processing and interacting with hypertext on the web. *Proceedings of the 30th International BCS Human Computer Interaction Conference: Fusion!* (p. 14). BCS Learning & Development Ltd.

Flesch, R. (1948). A new readability yardstick. *Journal of Applied Psychology*, *32*(3), 221-233.

Flowerday, T., Schraw, G., & Stevens, J. (2004). The role of choice and interest in reader engagement. *The Journal of Experimental Education*, *72*(2), 93-114.

Fogg, B. J., Soohoo, C., Danielson, D. R., Marable, L., Stanford, J., & Tauber, E. R. (2003). How do users evaluate the credibility of Websites?: A study with over 2,500 participants. *Proceedings of the 2003 conference on designing for user experiences*. ACM Digital Library.

Foltz, P. W. (2012). Comprehension, coherence, and strategies in hypertext and linear text. In *Hypertext and Cognition* (pp. 119-146). Routledge.

Fox, E., & Alexander, P. A. (2016). Learning to read. In R. E. Mayer, & P. A. Alexander (Eds.), *Handbook of Research on Learning and Instruction* (pp. 8-32). Taylor & Francis.

Fredin, E. (1997). Rethinking the news story for the internet: hyperstory prototypes and a model of the user. *Journalism and Mass Communication, 163*, 1-47.

Giebelhausen, R. (2015). What the tech is going on? Social media and your music classroom. *General Music Today*, *28*(2), 39-46.

Gilbert, D. T., Tafarodi, R. W., & Malone, P. S. (1993). You can't not believe everything you read. *Journal of Personality and Social Psychology*, *65*(2), 221-233.

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and Special Education*, *7*(1), 6-10.

Gould, J. D., & Grischkowsky, N. (1984). Doing the same work with hard copy and with cathode-ray tube (CRT) computer terminals. *Human Factors, 26,* 323-337.

Graesser, A. C., Millis, K. K., & Zwaan, R. A. (1997). Discourse comprehension. *Annual Review of Psychology*, *48*(1), 163-189.

Graff, M. (2005). Individual differences in hypertext browsing strategies. *Behaviour & Information Technology*, *24*(2), 93-99.

Häfner, A., Oberst, V., & Stock, A. (2014). Avoiding procrastination through time management: An experimental intervention study. *Educational Studies*, *40*(3), 352-360.

Hahnel, C., Goldhammer, F., Naumann, J., & Kröhne, U. (2016). Effects of linear reading, basic computer skills, evaluating online information, and navigation on reading digital text. *Computers in Human Behavior*, *55*, 486-500.

Hancock, G. M., Schmidt-Daly, T. N., Fanfarelli, J., Wolfe, J. L., & Szalma, J. L. (2016). Is E-Reader Technology Killing or Kindling the Reading Experience? *Ergonomics in Design*, *24*(1), 25–30. https://doi.org/10.1177/1064804615611269

Hardman, D., & Edwards, L. (1989). Lost in hyperspace': Cognitive mapping and navigation in a hypertext environment. *Hypertext: Theory into Practice*, 105-145.

Held, C., Kimmerle, J., & Cress, U. (2012). Learning by foraging: The impact of individual knowledge and social tags on web navigation processes. *Computers in Human Behavior*, *28*(1), 34-40.

Herold, B. (2014). Digital reading poses learning challenges for students. *The Education Digest*, *80*(1), 44-48.

Higgins, J., Russell, M., & Hoffmann, T. (2005). Examining the effect of computer-based passage presentation on reading test performance. *The Journal of*

Technology, Learning, and Assessment, 3(4). Retrieved from https://ejournals.bc.edu/ojs/index.php/jtla/article/view/1657

Hill, B. D., Elliott, E. M., Shelton, J. T., Pella, R. D., O'Jile, J. R., & Gouvier, W. D. (2010). Can we improve the clinical assessment of working memory? An evaluation of the Wechsler Adult Intelligence Scale–Third Edition using a working memory criterion construct. *Journal of Clinical and Experimental Neuropsychology*, *32*(3), 315-323.

Hofman, R., & van Oostendorp, H. (1999). Cognitive effects of a structural overview in a hypertext. *British Journal of Educational Technology*, *30*, 129-140.

Hofmann-Wellenhof, B., Legat, K., & Wieser, M. (2007). *Navigation: Principles of Positioning and Guidance*. Springer.

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing*, *2*(2), 127-160.

Hosp, J. L., & Suchey, N. (2014). Reading assessment: Reading fluency, reading fluently, and comprehension—Commentary on the special topic. *School Psychology Review*, *43*(1), 59-68.

Iglesias-Sarmiento, V., López, N. C., & Rodríguez, J. L. R. (2015). Updating executive function and performance in reading comprehension and problem solving. *Anales de Psicología*, *31*(1), 298-309. https://doi.org/10.6018/analesps.31.1.158111

Jääskeläinen, R. (2010). Think-aloud protocol. *Handbook of Translation Studies*, *1*, 371-374.

Jacobson, M. J., & Spiro, R. J. (1995). Hypertext learning environments, cognitive flexibility, and the transfer of complex knowledge: An empirical investigation. *Journal of Educational Computing Research, 12*(4), 301–333.

Jeong, H. (2010). A comparison of the influence of electronic books and paper books on reading comprehension, eye fatigue, and perception. *The Electronic Library, 30*, 390–408.

Jonassen, D., & Wang, S. (1990). Hypertext, Learning and Instructional Design. *Educational Media and Technology Yearbook, 15*.

Jung, J., Chan-Olmsted, S., Park, B., & Kim, Y. (2011). Factors affecting e-book reader awareness, interest, and intention to use. *New Media and Society, 14*, 204–224.

Kaakinen, J. K., & Hyona, J. (2005). Perspective effects on expository text comprehension: Evidence from think-aloud protocols, eyetracking, and recall. *Discourse Processes, 40*, 239-257.

Kamil, M. L., & Lane, D. (1998). Researching the relationship between technology and literacy: An agenda for the 21st century. *Handbook of Literacy and Technology: Transformations in a Post-Typographic World*, 323-341.

Karpicke, J. D., & Blunt, J. R. (2011). Retrieval practice produces more learning than elaborative studying with concept mapping. *Science, 331*, 772-775.

Kendeou, P., van den Broek, P., Helder, A., & Karlsson, J. (2014). A cognitive view of reading comprehension: Implications for reading difficulties. *Learning Disabilities Research and Practice, 29*(1). 10-16.

Kenward, M. G., & Roger, J. H. (1997). Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics*, 983-997.

Kerr, M. A., & Symons, S. E. (2006). Computerized presentation of text: Effects on children's reading of informational material. *Reading and Writing, 19*, 1-19.

Kingston, N. M. (2008). Comparability of computer- and paper- administered multiple-choice tests for K–12 populations: A synthesis. *Applied Measurement in Education*, *22*(1), 22-37. https://doi.org/10.1080/08957340802558326

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. Cambridge University Press.

Kirschner, P. A. (2002). Cognitive load theory: implications of cognitive load theory on the design of learning. *Learning and Instruction, 12(1)*, 1-10.

Kol, S., & Schcolnik, M. (2000). Enhancing screen reading strategies. *Calico Journal*, *18*, 67-80.

Kong, Y., Seo, Y. S., & Zhai, L. (2018). Comparison of reading performance on screen and on paper: A meta-analysis. *Computers & Education, 123*, 138-149. https://doi.org/10.1016/j.compedu.2018.05.005

Köpper, M., Mayr, S., & Buchner, A. (2016). Reading from computer screen versus reading from paper: does it still make a difference?. *Ergonomics*, *59*(5), 615-632.

Koriat, A. (2012). The relationships between monitoring, regulation and performance. *Learning and Instruction*, *22*(4), 296-298.

Koriat, A., & Ackerman, R. (2010). Metacognition and mindreading: Judgments of learning for self and other during self-paced study. *Consciousness and Cognition*, *19*(1), 251-264.

Koriat, A., Nussinson, R., & Ackerman, R. (2014). Judgments of learning depend on how learners interpret study effort. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(6), 1624-1637.

Kornell, N., & Bjork, R. A. (2007). The promise and perils of self-regulated study. *Psychonomic Bulletin & Review*, *14*(2), 219-224.

Kornell, N., Finn, B., Dunlosky, J., & Tauber, S. (2016). Self-regulated learning: An overview of theory and data. In J. Dunlosky & S. Tauber (Eds.), *The Oxford Handbook of Metamemory* (pp. 325-340). Oxford University Press.

Kretzschmar, F., Pleimling, D., Hosemann, J., Füssel, S., Bornkessel-Schlesewsky, I., & Schlesewsky, M. (2013). Subjective impressions do not mirror online reading effort: Concurrent EEG-eyetracking evidence from the reading of books and digital media. *PLOS ONE, 8*(2), 1-12.

Landi, N. (2010). An examination of the relationship between reading comprehension, higher-level and lower-level reading sub-skills in adults. *Reading and Writing*, *23*, 701-717.

Lauterman, T., & Ackerman, R. (2014). Overcoming screen inferiority in learning and calibration. *Computers in Human Behaviour, 35,* 455-463. https://doi.org/10.1016/j.chb.2014.02.046

Lawless, K. A., Brown, S. W., Mills, R., & Mayall, H. J. (2003). Knowledge, interest, recall and navigation: A look at hypertext processing. *Journal of Literacy Research*, *35*(3), 911-934.

Lawless, K. A., & Kulikowich, J. M. (1996). Understanding hypertext navigation through cluster analysis. *Journal of Educational Computing Research, 14,* 385-399.

Lawless, K. A., & Kulikowich, J. M. (1998). Domain knowledge, interest, and hypertext navigation: A study of individual differences. *Journal of Educational Multimedia and Hypermedia, 7,* 51-70.

Lawless, K. A., Mills, R., & Brown, S.W. (2002). Children's hypermedia navigational strategies. *Journal of Research on Computing in Education, 34,* 274-284.

Lawless, K. A., Schrader, P. G., & Mayall, H. J. (2007). Acquisition of information online: Knowledge, navigation and learning outcomes. *Journal of Literacy Research, 35,* 911-934.

Lee, M. J., & Tedder, M. C. (2003). The effects of three different computer texts on readers' recall: based on working memory capacity. *Computers in Human Behavior*, *19*(6), 767-783.

Lee, M. J., & Tedder, M. C. (2004). Introducing expanding hypertext based on working memory capacity and the feeling of disorientation: Tailored communication through effective hypertext design. *Journal of Educational Computing Research, 30*(3), 171-195.

Lee-Sammons, W. H., & Whitney, P. (1991). Reading perspectives and memory for text: An individual differences analysis. *Journal of Experimental Psychology:*

Learning, Memory, and Cognition, 17(6), 1074-1081. https://doi.org/10.1037/0278-7393.17.6.1074.

Legge, G. E., Cheung, S. H., Yu, D., Chung, S. T. L., Lee, H.-W., & Owens, D. P. (2007). The case for the visual span as a sensory bottleneck in reading. *Journal of Vision, 7*, 1-15. https://doi.org/10.1167/7.2.9

Leu, D. J., Kinzer, C. K., Coiro, J. L., & Cammack, D. W. (2004). Toward a theory of new literacies emerging from the Internet and other information and communication technologies. *Theoretical Models and Processes of Reading, 5,* 1570-1613.

Leu, D. J., Castek, J., Hartman, D., Coiro, J., Henry, L., Kulikowich, J., et al. (2005). *Evaluating the development of scientific knowledge and new forms of reading comprehension during online learning*. Final report presented to the North Central Regional Educational Laboratory/Learning Point Associates. www.newliteracies.uconn.edu/ncrel.html

Li, L. Y., Tseng, S. T., & Chen, G. D. (2016). Effect of hypertext highlighting on browsing, reading, and navigational performance. *Computers in Human Behavior, 54,* 318-325.

Liedke, L. (2019, September 20). 100+ internet statistics and facts for 2019. Website Hosting Rating. https://www.websitehostingrating.com/internet-statistics-facts/

Liu, Z. (2005). Reading behavior in the digital environment: Changes in reading behavior over the past ten years. *Journal of Documentation, 61*(6), 700–712. https://doi.org/10.1108/00220410510632040

Liu, Z. (2012). Digital reading: An overview. *Chinese Journal of Library and Information Science, 5*, 85-94.

Logie, R. H., Zucco, G. M., & Baddeley, A. D. (1990). Interference with visual short-term memory. *Acta Psychologica*, *75*(1), 55-74.

Lorch Jr, R. F., & Lorch, E. P. (1996). Effects of organizational signals on free recall of expository text. *Journal of Educational Psychology, 88,* 38-48. https://doi.org/10.1037/0022-0663.88.1.38

Lucassen, T., Muilwijk, R., Noordzij, M. L., & Schraagen, J. M. (2013). Topic familiarity and information skills in online credibility evaluation. *Journal of the American Society for Information Science and Technology*, *64*, 254-264.

Ma, L., Chang, L., Chen, X., & Zhou, R. (2017). Working memory test battery for young adults: Computerized working memory assessment. *PloS One*, *12*, 1-19.

Madrid, I. R., Van Oostendorp, H., & Puerta Melguizo, M. C. (2009). The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behaviour, 25,* 66–75. https://doi.org/10.1016/j.chb.2008.06.005

Magliano, J. P., Trabasso, T., & Graesser, A. C. (1999). Strategic processing during comprehension. *Journal of Educational Psychology*, *91,* 615–629.

Maki, R. H. (1995). Accuracy of metacomprehension judgments for questions of varying importance levels. *American Journal of Psychology, 108*, 327–344.

Mangen, A., Olivier, G., & Velay, J. L. (2019). Comparing comprehension of a long text read in print book and on kindle: Where in the text and when in the story? *Frontiers in Psychology, 10*, 38-49. https://doi.org/10.3389/fpsyg.2019.00038

Mangen, A., Waldermo, B. R., & Brønnick, K. (2013). Reading linear texts on paper versus computer screen: effects on reading comprehension. *International Journal of Educational Research, 58,* 61-68. https://doi.org/10.1016/j.ijer.2012.12.002

Mangen, A., & Kuiken, D. (2014). Lost in an iPad: Narrative engagement on paper and tablet. *Scientific Study of Literature, 4*(2), 150-177. https://doi.org/10.1075/ssol.4.2.02man

Maras, D., Flament, M. F., Murray, M., Buchholz, A., Henderson, K. A., Obeid, N., & Goldfield, G. S. (2015). Screen time is associated with depression and anxiety in Canadian youth. *Preventive Medicine, 73*, 133-138.

Marchionini, G. (1995). *Information seeking in electronic environments*. Cambridge University Press.

Marchionini, G. (2019). Search, sense making and learning: closing gaps. *Information and Learning Sciences*, *120*(1), 74-86.

Margolin, S. J., Driscoll, C., Toland, M. J., & Kegler, J. L. (2013). E-readers, computer screens, or paper: Does reading comprehension change across media platforms?. *Applied Cognitive Psychology, 27,* 512-519.

Martelli, M., Di Filippo, G., Spinelli, D., & Zoccolotti, P. (2009). Crowding, reading, and developmental dyslexia. *Journal of Vision*, *9*(4), 1-14.

Mayer, R. E. (1979). Twenty years of research on advance organizers: Assimilation theory is still the best predictor of results. *Instructional Science, 8,* 133-167.

Mayes, D. K., Sims, V. K., & Koonce, J. M. (2001). Comprehension and workload differences for VDT and paper-based reading. *International Journal of Industrial Ergonomics, 28,* 367–378.

McDonald, S., & Stevenson, R. J. (1998). Effects of text structure and prior knowledge of the learner on navigation in hypertext. *Human Factors*, *40,* 18-27.

McNamara, D. S., & Magliano, J. (2009). Toward a Comprehensive Model of Comprehension. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. 51, pp. 297-384). Academic Press. https://doi.org/10.1016/S0079-7421(09)51009-2

McNamara, D. S., & Scott, J. L. (1999). Training Self Explanation and Reading Strategies. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *43,* 1156-1160.

Merga, M. K. (2014). Are teenagers really keen digital readers?: Adolescent engagement in ebook reading and the relevance of paper books today. *English Australia Journal*, *49*, 27–37.

Merga, M. K. (2015). Do Adolescents Prefer Electronic Books to Paper Books?. *Publications*, *3*(4), 237-247. https://doi.org/10.3390/publications3040237

Mesquita, G., & Reimão, R. (2007). Nightly use of computer by adolescents: its effect on quality of sleep. *Arquivos de Neuro-Psiquiatria*, *65*(2B), 428-432.

Metcalfe, J. (2002). Is study time allocated selectively to a region of proximal learning?. *Journal of Experimental Psychology: General*, *131*(3), 349-363.

Metcalfe, J., & Kornell, N. (2005). A region of proximal learning model of study time allocation. *Journal of Memory and Language*, *52*(4), 463-477.

Millis, K., Magliano, J., & Todaro, S. (2006). Measuring discourse-level processes with verbal protocols and latent semantic analysis. *Scientific Studies of Reading*, *10*(3), 225-240.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex 'front lobe' tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100. https://doi.org/10.1006/cogp.1999.0734

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. Cambridge University Press.

Mizrachi, D., Salaz, A. M., Kurbanoglu, S., & Boustany, J. (2018). Academic reading format preferences and behaviors among university students worldwide: A comparative survey analysis. *PLoS One, 13,* 1-32. https://doi.org/10.1371/journal.pone.0197444

Mohammadi Bytamar, J., Zenoozian, S., Dadashi, M., Saed, O., Hemmat, A., & Mohammadi, G. (2017). Prevalence of Academic Procrastination and Its Association with Metacognitive Beliefs in Zanjan University of Medical Sciences, Iran. *Journal of Medical Education Development*, *10*, 84-97.

Muir, L., & Hawes, G. (2013). The case for e-book literacy: Undergraduate students' experience with e-books for course work. *The Journal of Academic Librarianship, 39*(3), 260–274. https://doi.org/10.1016/j.acalib.2013.01.002

Murphy, P. K., Long, J. F., Holleran, T. A., & Esterly, E. (2003). Persuasion online or on paper: A new take on an old issue. *Learning and Instruction, 13*(5), 511-532.

Myrberg, C., & Wiberg, N. (2015). Screen vs. paper: what is the difference for reading and learning? *Insights, 28*(2), 49-54.

Naumann, J. (2008). Log file analysis in hypertext research: An overview, a meta-analysis, and some suggestions for future research. In *Workshop on cognition and the web: Information processing, comprehension and learning* (pp. 53-56). University of Granada.

Naumann, J., Richter, T., Flender, J., Christmann, U., & Groeben, N. (2007). Signaling in expository hypertexts compensates for deficits in reading skill. *Journal of Educational Psychology, 99*(4), 791-807.

Naumann, J., Richter, T., Christmann, U., & Groeben, N. (2008). Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext. *Learning and Individual Differences, 18*(2), 197-213. http://doi.org/10.1016/j.lindif.2007.08.007.

Naumann, J., & Salmerón, L. (2016). Does navigation always predict performance? Effects of relevant page selection on digital reading performance are moderated by offline comprehension skills. *The International Review of Research in Open and Distributed Learning, 17,* 42-59.

Nelson, T H. (1965). Complex information processing: A file structure for the complex, the changing and the indeterminate. In L. Winner (Ed.), *Association for Computing Machinery Proceedings of the 20th National Conference* (pp. 84-100). ACM Press. http://doi.org/10.1145/800197.806036.

Nelson, T. H. (1967). Getting it out of our system. In G. Schechter (Ed.), *Information Retrieval: A Critical Review* (pp. 191-210). Thompson Books.

Nelson, T. O., & Narens, L. (1994). Why investigate metacognition? In J. Metcalfe & A.P. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 1-25). MIT Press.

Neumann, M. M. (2016). Young children's use of touch screen tablets for writing and reading at home: Relationships with emergent literacy. *Computers & Education*, *97*, 61-68.

Nilsson, R. M., & Mayer, R. E. (2002). The effects of graphic organizers giving cues to the structure of a hypertext document on users' navigation strategies and performance. *International Journal of Human-Computer Studies, 57*(1), 1-26.

Norman, E., & Furnes, B. (2016). The relationship between metacognitive experiences and learning: Is there a difference between digital and non-digital study media? *Computers in Human Behavior, 54*, 301-309.

Nouwens, S., Groen, M. A., & Verhoeven, L. (2016). How storage and executive functions contribute to children's reading comprehension. *Learning and Individual Differences*, *47*, 96-102.

Nouwens, S., Groen, M. A., & Verhoeven, L. (2017). How working memory relates to children's reading comprehension: the importance of domain-specificity in storage and processing. *Reading and Writing*, *30*(1), 105-120.

Noyes, J., & Garland, K. (2006). Explaining students' attitudes toward books and computers. *Computers in Human Behavior*, *22*(3), 351-363.

Noyes, J., Garland, K., & Robbins, L. (2004). Paper-based versus computer-based assessment: Is workload another test mode effect? *British Journal of Educational Technology, 35*, 111-113.

Ong, C. N., B., Hoong, T., & Phoon, W. O. (1981). Visual and muscular fatigue in operators using visual display terminals. *Journal of Human Ergology, 10*, 161–171.

Onwuegbuzie, A. J. (2004). Academic procrastination and statistics anxiety. *Assessment & Evaluation in Higher Education, 29*(1), 3-19.

O'Regan, J. K. (1990). Eye movements and reading. In E. Kowler (Ed.), *Eye movements and their role in visual and cognitive processes* (pp. 395–453). Elsevier.

Organisation for Economic Co-operation and Development (OECD). (2009). *PISA 2009 assessment framework. Key competencies in reading, mathematics, and science*. OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2011). *PISA 2009 Results: Students on line*. OECD Publishing.

Otter, M., & Johnson, H. (2000). Lost in hyperspace: Metrics and mental models. *Interacting with Computers, 13*, 1-40.

Ozuru, Y., Dempsey, K., & McNamara, D. S. (2009). Prior knowledge, reading skill, and text cohesion in the comprehension of science texts. *Learning and Instruction, 19*(3), 228-242.

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science, 32*(1), 1-8.

Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*, *45*(3), 255-287.

Pang, A. S. K. (1998). Hypertext, the next generation: A review and research agenda. *First Monday, 3*(11), 1-13.

Pazzaglia, F., Toso, C., & Cacciamani, S. (2008). The specific involvement of verbal and visuo-spatial working memory in hypermedia learning. *British Journal of Educational Technology*, *39*, 110–124.

Pearson, P. D., & Dole, J. A. (1987). Explicit comprehension instruction: A review of research and a new conceptualization of instruction. *The Elementary School Journal, 88*, 151–165.

Perfetti, C., & Adlof, S.M. (2012). Reading comprehension: A conceptual framework from word meaning to text meaning. In J. Sabatini, E. Albro, & T. O'Reilly (Eds.), *Measuring up: Advances in how we assess reading ability* (pp. 3–20). Rowman & Littlefield Publishers, Inc.

Perrin, A. (2016, September 1). *Book Reading 2016*. Pew Research Center. https://www.pewresearch.org/internet/2016/09/01/book-reading-2016/

Perrin, A. (2019, September 25). *One-in-five Americans now listen to audiobooks*. Pew Research Center. https://www.pewresearch.org/fact-tank/2019/09/25/one-in-five-americans-now-listen-to-audiobooks/

Petrov, Y., & Meleshkevich, O. (2011). Locus of spatial attention determines inward–outward anisotropy in crowding. *Journal of Vision*, *11*(4), 1-11.

Petter, O. (2019, August 2). Millennials suffer ‘load rage’ when download speeds are longer than minute. Independent. https://www.independent.co.uk/life-style/millennials-load-rage-slow-download-speed-content-anger-a9035281.html

Pfost, M., Dörfler, T., & Artelt, C. (2013). Students' extracurricular reading behavior and the development of vocabulary and reading comprehension. *Learning and Individual Differences, 26,* 89-102. http://doi.org/10.1016/j.lindif.2013.04.008

Pham, A. V., & Hasson, R. M. (2014). Verbal and visuospatial working memory as predictors of children's reading ability. *Archives of Clinical Neuropsychology, 29*(5), 467-477.

Potelle, H., & Rouet, J.-F. (2003). Effects of content representation and readers’ prior knowledge on the comprehension of hypertext. *International Journal of Human–Computer Studies, 5*, 327–345.

Pommerich, M. (2004). Developing computerized versions of paper-and-pencil tests: Mode effects for passage-based tests. *The Journal of Technology, Learning and Assessment*, *2*(6), 1-45.

Precel, K., Eshet-Alkalai, Y., & Alberton, Y. (2009). Pedagogical and design aspects of a blended learning course. *The International Review of Research in Open and Distance Learning, 10*(2), 1-16.

RAND Reading Study Group. (2002). *Reading for understanding: Toward an R&D program in reading comprehension*. Rand.

Randall, J. G., Oswald, F. L., & Beier, M. E. (2014). Mind-wandering, cognition, and performance: A theory-driven meta-analysis of attention regulation. *Psychological Bulletin, 140*(6), 1411-1431.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 85*, 618-660. http://doi.org/10.1037/0033-2909.85.3.618

Rayner, K. (2008). The role of computational models and experimental data in understanding eye movements during reading. *International Journal of Psychology, 43*, 189–190.

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z reader model of eye-movement control in reading: Comparisons to other models. *The Behavioral and Brain Sciences, 26*, 445–476. http://doi.org/10.1017/S0140525X03000104

Rey, P., & Meyer, J. J. (1980). Visual impairments and their objective correlates. In E. Grandjean & E. Vigliani (Eds.), *Ergonomic aspects of visual display terminals* (pp. 77-83). Taylor and Francis.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *The Quarterly Journal of Experimental Psychology*, *62*(8), 1457-1506.

Richardson, J., Dillon, A., & MacKnight, C. (1988). *The manipulation of screen-presented text*. HUSAT Memo 431. Loughborough University of Technology.

Rockinson-Szapkiw, A. J., Courduff, J., Carter, K., & Bennett, D. (2013). Electronic versus traditional print textbooks: A comparison study on the influence of university students' learning. *Computers & Education, 63,* 259–266.

Rojeski, M. (2012). User perceptions of ebooks versus print books for class reserves in an academic library. *Reference Services Review, 40*(2), 228-241.

Ross, B., Pechenkina, E., Aeschliman, C., & Chase, A.-M. (2017). Print vs. digital texts: Understanding the research and challenging the dichotomies. *Research in Learning Technology, 25*, 1-12. https://doi.org/10.25304/rlt.v25.1976

Rothblum, E. D., Solomon, L. J., & Murakami, J. (1986). Affective, cognitive, and behavioral differences between high and low procrastinators. *Journal of Counselling Psychology, 33*(4), 387-394.

Rouet, J. -F., Dillon, A., Levonen, J. J., & Spiro, R. J. (Eds.). (1996). *Hypertext and cognition*. Psychology Press.

Rouet, J.-L., Favart, M., Britt, M. A., & Perfetti, C. A. (1997). Studying and using multiple documents in history: Effects of discipline expertise. *Cognition and Instruction, 15,* 85-106.

Rouet, J.-F., & Le Bigot, L. (2007). Effects of academic training on metatextual knowledge and hypertext navigation. *Metacognition and Learning, 2*, 157-168. https://doi.org/10.1007/s11409-007-9011-z

Salmerón, L., Baccino, T., Cañas, J. J., Madrid, R. I., & Fajardo, I. (2009). Do graphical overviews facilitate or hinder comprehension in hypertext?. *Computers & Education*, *53*(4), 1308-1319.

Salmerón, L., Cañas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading strategies and hypertext comprehension. *Discourse Processes, 40*(3), 171-191. https://doi.org/10.1207/s15326950dp4003_1

Salmerón, L., Cerdán, R., & Naumann, J. (2015). How adolescents navigate Wikipedia to answer questions. *Infancia y Aprendizaje: Journal for the Study of Education and Development, 38*, 435-471.

Salmerón, L., García, A., & Vidal-Abarca, E. (2018). The development of adolescents' comprehension-based Internet reading skills. *Learning and Individual Differences, 61*, 31-39. https://doi.org/10.1016/j.lindif.2017.11.006

Salmerón, L., Kintsch, W., & Kintsch, E. (2010). Self-regulation and link selection strategies in hypertext. *Discourse Processes*, *47*(3), 175-211.

Salmerón, L., Naumann, J., García, V., & Fajardo, I. (2017). Scanning and deep processing of information in hypertext: an eye tracking and cued retrospective think-aloud study. *Journal of Computer Assisted Learning*, *33*(3), 222-233.

Salmerón, L., Strømsø, H. I., Kammerer, Y., Stadtler, M., & van den Broek, P. (2018). Comprehension processes in digital reading. In M. Barzillai, J. Thomson, S. Schroeder, & P. van den Broek (Eds.), *Learning to read in a digital world* (pp. 91-120). John Benjamins Publishing Company.

Sanchez, C. A., & Wiley, J. (2009). To scroll or not to scroll: Scrolling, working memory capacity, and comprehending complex texts. *Human Factors*, *51*(5), 730-738.

Sandberg, K. E. (2013). Hypertext: Its nature and challenges for college students. *Journal of College Reading and Learning*, *44*(1), 51-71.

Selwyn, N., & Gorard, S. (2016). Students' use of Wikipedia as an academic resource—Patterns of use and perceptions of usefulness. *The Internet and Higher Education*, *28*, 28-34.

Seufert, T., & Brünken, R. (2006). Cognitive load and the format of instructional aids for coherence formation. *Applied Cognitive Psychology, 20*, 321–331.

Scheiter, K., Ackerman, R., & Hoogerheide, V. (2020). Looking at mental effort appraisals through a metacognitive lens: Are they biased?. *Educational Psychology Review*, 1-25.

Schneps, M. H., O'Keeffe, J. K., Heffner-Wong, A., & Sonnert, G. (2010). Using technology to support STEM reading. *Journal of Special Education Technology, 25*, 21-34. https://doi.org/10.1177/016264341002500304

Schneps, M. H., Thomson, J. M., Sonnert, G., Pomplun, M., Chen, C., & Heffner-Wong, A. (2013). Shorter lines facilitate reading in those who struggle. *PloS One*, *8*(8), 71-161.

Schwartz, N. H., Andersen, C., Hong, N., Howard, B., & McGee, S. (2004). The influence of metacognitive skills on learner's memory of information in a hypermedia environment. *Journal of Educational Computing Research, 31*(7), 77-93.

Selwyn, N., & Gorard, S. (2016). Students' use of Wikipedia as an academic resource—Patterns of use and perceptions of usefulness. *The Internet and Higher Education*, *28*, 28-34.

Shang, H. F. (2016). Online Metacognitive Strategies, Hypermedia Annotations, and Motivation on Hypertext Comprehension. *Journal of Educational Technology & Society, 19*(3), 321-334.

Shapiro, A. M. (1998). Promoting active learning: The role of system structure in learning from hypertext. *Human–Computer Interaction, 13,* 1–35.

Shishkovskaya, J., Sokolova, E., & Chernaya, A. (2015). "Paperless" foreign languages teaching. *Procedia-Social and Behavioral Sciences, 206,* 232-235.

Sidi, Y., Ophir, Y., & Ackerman, R. (2016). Generalizing screen inferiority-does the medium, screen versus paper, affect performance even with brief tasks?. *Metacognition and Learning*, *11*(1), 15-33.

Sidi, Y, Shpigelman, M., Zalmanov, H., & Ackerman, R. (2017). Understanding metacognitive inferiority on screen by exposing cues for depth of processing. *Learning and Instruction, 51,* 61-73.

Sidi, Y., Ackerman, R., & Erez, A. (2018). Feeling happy and (over) confident: the role of positive affect in metacognitive processes. *Cognition and Emotion, 32,* 876-884.

Singer, L. M., & Alexander, P. A. (2017). Reading across mediums: Effects of reading digital and print texts on comprehension and calibration. *Learning, Instruction, and Cognition*, *85*(1), 155-172. https://doi.org/10.1080/00220973.2016.1143794

Singer, L. M., & Alexander, P. A. (2017). Reading on paper and digitally: What the past decades of empirical research reveal. *Review of Educational Research, 87*(6), 1007-1041. https://doi.org/10.3102/0034654317722961

Singer, M., & Ritchot, K. F. (1996). The role of working memory capacity and knowledge access in text inference processing. *Memory & Cognition*, *24*(6), 733-743.

Son, L. K., & Metcalfe, J. (2000). Metacognitive and control strategies in study-time allocation. *Journal of Experimental Psychology Learning Memory and Cognition*, *26*(1), 204-221.

Spiro, R. J., Coulson, R. L., Feltovich, P. J., & Anderson, D. K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. *The Tenth Annual Conference of the Cognitive Science Society*. Lawrence Erlbaum Associates.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (2012). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Constructivism in education* (pp. 103-126). Routledge.

Spiro, R. J., & Jehng, J. (1990). Cognitive flexibility and hypertext: theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R. Spiro (Eds.), *Cognition, education, and multimedia: Exploring ideas in high technology* (pp. 163–205). Lawrence Erlbaum Associates.

Steel, P., & Ferrari, J. (2013). Sex, Education and Procrastination: An Epidemiological Study of Procrastinators' Characteristics from a Global Sample. *European Journal of Personality*, *27*(1), 51-58.

Stern, P., & Shalev, L. (2013). The role of sustained attention and display medium in reading comprehension among adolescents with ADHD and without it. *Research in Developmental Disabilities, 34,* 431–439.

Stoop, J., Kreutzer, P., & Kircz, J. (2013a). Reading and learning from screens versus print: a study in changing habits: Part 1–reading long information rich texts. *New Library World, 114*(7/8), 284-300.

Stoop, J., Kreutzer, P., & G. Kircz, J. (2013b). Reading and learning from screens versus print: a study in changing habits: Part 2–comparing different text structures on paper and on screen. *New Library World, 114,* 371-383.

Sullivan, S. A., Gnesdilow, D., & Puntambekar, S. (2011). Navigation behaviors and strategies used by middle school students to learn from a science hypertext. *Journal of Educational Multimedia and Hypermedia, 20,* 387-423.

Sullivan, S. A., & Puntambekar, S. (2015). Learning with digital texts: Exploring the impact of prior domain knowledge and reading comprehension ability on navigation and learning outcomes. *Computers in Human Behavior, 50,* 299-313.

Swanson, H. L., & Jerman, O. (2007). The influence of working memory on reading growth in sub-groups of children with reading disabilities. *Journal of Experimental Child Psychology, 96,* 249-283. https://doi.org/10.1016/j.jecp.2006.12.004

Sweller, J. (2011). Cognitive load theory. *Psychology of Learning and Motivation*, 55, 37-76.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General, 119*(2), 176-192.

Sweller, J., van Merrienboer, J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Thain, M. (2018). Distracted Reading: Acts of Attention in the Age of the Internet. *DHQ: Digital Humanities Quarterly*, *12*(2), 1-5.

Theng, Y. L., & Thimbleby, H. W. (1998). Addressing Design and Usability Issues in Hypertext and on the World Wide Web by Re-Examining the “Lost in Hyperspace" Problem. *Journal of Universal Computer Science*, *4*(11), 839-855.

Theng, Y. L., Thimbleby, H., & Jones, M. (1996). ‘Lost in hyperspace': Psychological problem or bad design. *APCHI, 96,* 387-396.

Thiede, K. W., & Dunlosky, J. (1999). Toward a general model of self-regulated study: An analysis of selection of items for study and self-paced study time. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(4), 1024-1037.

Trabasso, T., & Magliano, J. P. (1996). Conscious understanding during text comprehension. *Discourse Processes, 21,* 255-288.

Tveit, A.K., & Mangen, A. (2014). A joker in the class: Teenage readers’ attitudes and preferences to reading on different devices. *Library and Information Science Research, 36,* 179-184.

Undorf, M., and Ackerman, R. (2017). The puzzle of study time allocation for the most challenging items. *Psychonomic Bulletin & Review*, *24*, 2003-2011. https://doi.org/10.3758/s13423-017-1261-4

Unsworth, N., & McMillan, B.D. (2013). Mind wandering and reading comprehension: Examining the roles of working memory capacity, interest, motivation, and topic experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(3), 832-842. https://doi.org/10.1007/s12671-016-0615-8

van den Broek, P., Mouw, J. M., & Kraal, A. (2016). *Individual differences in reading comprehension*. In P. Afflerbach (Ed.), *Handbook of individual differences in reading: Reader, text, and context* (pp. 138-150). Routledge.

van den Broek, P., Rapp, D., & Kendeou, P. (2005). Integrating memory-based and constructionist processes in accounts of reading comprehension. *Discourse Processes, 39*(2), 299-316.

van den Broek, P., White, M.J., Kendeou, P. & Carlson, S. (2009). Reading between the lines: Developmental and individual differences in cognitive processes in reading comprehension. In R. K. Wagner, C. Schatschneider & C. Phythian-Sence (Eds.), *Beyond decoding: The behavioral and biological foundations of reading comprehension* (pp. 107-123). The Guildford Press.

Van Den Haak, M., De Jong, M., & Jan Schellens, P. (2003). Retrospective vs. concurrent think-aloud protocols: testing the usability of an online library catalogue. *Behaviour & Information Technology*, *22*, 339-351.

Van Gog, T., Paas, F., Van Merriënboer, J. J., & Witte, P. (2005). Uncovering the problem-solving process: Cued retrospective reporting versus concurrent and

retrospective reporting. *Journal of Experimental Psychology: Applied*, *11*(4), 237-244.

Veenman, M. V., Wilhelm, P., & Beishuizen, J. J. (2004). The relation between intellectual and metacognitive skills from a developmental perspective. *Learning and Instruction*, *14*(1), 89-109.

Verdi, M. P., Crooks, S. M., & White, D. R. (2014). Learning effects of print and digital geographic maps. *Journal of Research on Computing in Education, 35,* 290-302.

Vidal-Abarca, E., Gilabert, R., Ferrer, A., Ávila, V., Martínez, T., Mañá, A., Llorens, A.C., Gil, L., Cerdán, R., Ramos, L., & Serrano, M. Á. (2014). TuinLEC, an intelligent tutoring system to improve reading literacy skills. *Infancia y Aprendizaje, 37*, 25-56. https://doi.org/10.1080/02103702.2014.881657

Vogels, E. A., Perrin, A., Raainie, L., & Anderson, M. (2020, April 30). 53% of Americans Say the Internet Has Been Essential During the COVID-19 Outbreak. Pew Research Center. *53% of Americans Say the Internet Has Been Essential During the COVID-19 Outbreak*. Pew Research Center. https://www.pewresearch.org/internet/2020/04/30/53-of-americans-say-the-internet-has-been-essential-during-the-covid-19-outbreak/

Vörös, Z., Rouet, J. F., & Pléh, C. (2011). Effect of high-level content organizers on hypertext learning. *Computers in Human Behavior*, *27*(5), 2047-2055.

Walczyk, J. J. (1995). A test of the compensatory-encoding model. *Reading Research Quarterly, 30*, 396–408.

Walczyk, J. J., & Griffith-Ross, D. A. (2007). How important is reading skill fluency for comprehension?. *The Reading Teacher*, *60*(6), 560-569.

Walczyk, J. J., Kelly, K. E., Meche, S. D., & Braud, H. (1999). Time limitations enhance reading comprehension. *Contemporary Educational Psychology*, *24*(2), 156-165.

Walker, S., Black, A., Bessemans, A., Bormans, K., Renckens, M., & Barratt, M. (2018). Designing digital texts for beginner readers. In M. Barzillai, J. Thomson, S. Schroeder, & P. van den Broek (Eds.), *Learning to read in a digital world* (pp. 17-31). John Benjamins Publishing Company.

Walhout, J., Brand-Gruwel, S., Jarodzka, H., Van Dijk, M., De Groot, R., & Kirschner, P. A. (2015). Learning and navigating in hypertext: Navigational support by hierarchical menu or tag cloud?. *Computers in Human Behavior*, *46*, 218-227.

Walsh, G. (2016). Screen and paper reading research–A literature review. *Australian Academic & Research Libraries*, *47*(3), 160-173.

Wang, Y. H. (2016). Reading strategy use and comprehension performance of more successful and less successful readers: A think-aloud study. *Educational Sciences: Theory & Practice*, *16*, 1789-1813.

Wang, S., Jiao, H., Young, M. J., Brooks, T. & Olson, O. (2007). Comparability of computer-based and paper-and-pencil testing in K–12 reading assessments. A meta-analysis of testing mode effects. *Educational and Psychological Measurement, 68*(1), 5-24. https://doi.org/10.1177/0013164407305592

Wechsler, D., & Naglieri, J. A. (2006). *Wechsler Nonverbal Scale of Ability: Technical and interpretive manual*. The Psychological Corporation.

Wilkinson, R. T., & Robinshaw, H. M. (1987). Proof-reading: VDU and paper text compared for speed, accuracy and fatigue. *Behaviour & Information Technology*, *6*(2), 125-133.

Winne, P. H. (1995). Inherent details in self-regulated learning. *Educational Psychologist*, *30*, 173-187.

Winne, P. H. (2001). Self-regulated learning viewed from models of information processing. *Self-regulated Learning and Academic Achievement: Theoretical Perspectives*, *2*, 153-189.

Winne, P. H., & Perry, N. E. (2000). Measuring self-regulated learning. In *Handbook of self-regulation* (pp. 531-566). Academic Press.

Wolf, M., & Barzillai, M. (2009). The importance of deep reading. *Educational Leadership*, *6*(6), 32-37.

Wolverton, G. S., & Zola, D. (1983). The temporal characteristics of visual information extraction during reading. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 41-51). Academic Press.

Wood, B., Rea, M. S., Plitnick, B., & Figueiro, M. G. (2013). Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. *Applied Ergonomics*, *44*(2), 237-240.

Wood, Z. (2017, March 17). Paperback fighter: sales of physical books now outperform digital titles. The Guardian. https://www.theguardian.com/books/2017/mar/17/paperback-books-sales-outperform-digital-titles-amazon-ebooks

Woody, W. D., Daniel, D. B., & Baker, C. A. (2010). E-books or textbooks: Students prefer textbooks. *Computers and Education, 55*, 945-948.

Wu, J. Y., & Xie, C. (2018). Using time pressure and note-taking to prevent digital distraction behavior and enhance online search performance: Perspectives from the load theory of attention and cognitive control. *Computers in Human Behavior*, *88*, 244-254.

Wylie, J., & McGuinness, C. (2004). The interactive effects of prior knowledge and text structure on memory for cognitive psychology texts. *British Journal of Educational Psychology*, *74*, 497-514.

Wylie, J., Thomson, J., Leppänen, P. H., Ackerman, R., Kanniainen, L., & Prieler, T. (2018). Cognitive processes and digital reading. In M. Barzillai, J. Thomson, S. Schroeder, & P. van den Broek (Eds.), *Learning to read in a digital world* (pp. 17-57). John Benjamins Publishing Company.

Young, J. (2014). A study of print and computer-based reading to measure and compare rates of comprehension and retention. *New Library World*, *115*, 376-393.

Zandvliet, D., & Farragher, P. (1997). A comparison of computer-administered and written tests. *Journal of Research on Computing in Education, 29*, 423-438.

Zhang, H., & Salvendy, G. (2001). The implications of visualization ability and structure preview design for Web information search tasks. *International Journal of Human-Computer Interaction*, *13*(1), 75-95.

Ziefle, M. (1998). Effects of display resolution on visual performance. *Human Factors, 40*, 554-568.

Zimmerman, B. J. (1986). Becoming a self-regulated learner: Which are the key subprocesses? C*ontemporary Educational Psychology*, *11*(4), 307-313. https://doi.org/10.1016/0361-476X(86)90027-5

Appendices

Appendix A: Battle of Trafalgar Text (Study 1 and 2)

Global Power

The Battle of Trafalgar was to witness both the defeat of Napoleon Bonaparte's plans to invade Britain, and the death of Admiral Lord Nelson. It was never going to be any ordinary battle, and quickly acquired a heightened, almost magical, reality.

During the engagement at Trafalgar, on 21 October 1805, the Royal Navy annihilated the greatest threat to British security for 200 years, but lost Britain's national hero in the process. Little wonder the battle transcended the mundane calculation of ships and men, victory and defeat. It guaranteed Britain's control of the oceans, the basis of her global power for over a century.

By 1805 Nelson was already a national hero, and considered the ultimate naval commander. His elevated conception of war ensured that every battle he fought was used to solve major strategic problems, and his many successes ensured he was the only contemporary to rival Bonaparte as ultimate exemplar of total war. Nor did Bonaparte disagree - he kept a bust of Nelson in his private quarters.

Nelson developed the art of war at sea to the new, terrible form he characterised as 'annihilation' to counter the war effort of Napoleonic France. He did so by taking the command system of Admiral Sir John Jervis, the tough old officer who taught him how to keep a fleet efficient, and melding it with the genius for battle and strategy he developed while serving under Admiral Lord Hood.

Nelson used this combination of strategic flair and practical management to help Britain survive the 22 year struggle with Revolutionary and Napoleonic France. He understood that invasion by France was the least of Britain's worries - the real threat was the destruction of her global commercial system.

In 1803 the Peace of Amiens - a temporary armed truce between Britain and France - broke down, and for nearly two years British strategy rested on the defensive, waiting for the French navy to make the first move. Late in 1804, however, Spain joined the war as an ally of France, giving Napoleon the ships he needed to challenge Britain.

This was the context of Trafalgar. Napoleon was looking for an opportunity to strike at Britain, without having to fight Nelson and the Royal Navy - while all his attempts to attack British interests were thwarted by expert seamen who countered his every move.

By September 1805, however, Villeneuve's fleet had found shelter at Cadiz, and was ideally positioned to attack British trading ships or Britain itself. It had to be destroyed.

Admiral Lord Nelson

Born on 29 September 1758 in Burnham Thorpe, Norfolk, Horatio Nelson was the sixth of the 11 children of a clergyman. He joined the navy aged 12, on a ship commanded by a maternal uncle. He became a captain at 20, and saw service in the West Indies, Baltic and Canada. He married Frances Nisbet in 1787 in Nevis, and returned to England with his bride to spend the next five years on half-pay, frustrated at the lack of a command.

When Britain entered the French Revolutionary Wars in 1793, Nelson was given command of the Agamemnon. He served in the Mediterranean, helped capture Corsica and saw battle at Calvi (where

he lost the sight in his right eye). He would later lose his right arm at the Battle of Santa Cruz de Tenerife in 1797.

Over the period 1794 to 1805, under Nelson's leadership, the Royal Navy proved its supremacy over the French. As a commander he was known for bold action and the occasional disregard of orders from his seniors. This defiance brought him victories against the Spanish off Cape Vincent in 1797, and at the Battle of Copenhagen four years later, where he ignored orders to cease action by putting his telescope to his blind eye and claiming he couldn't see the signal to withdraw.

At the Battle of the Nile in 1798, he successfully destroyed Napoleon's fleet and thus his bid for a direct trade route to India. Nelson's next posting took him to Naples, where he fell in love with Emma, Lady Hamilton. Although they remained in their respective marriages, Nelson and Emma Hamilton considered each other soul-mates and had a child together, Horatia, in 1801. Earlier that same year, Nelson was promoted to vice-admiral.

Admiral Lord Nelson and Lady Hamilton

Nelson's affair with Emma Hamilton was the biggest scandal of the age. Their actual liaison lasted only six years, but it transformed their lives, their respective positions in society, and the public's perception of them both.

Horatio Nelson first met Lady Hamilton on 12 September 1793. He was a 35-year-old post captain and she was the 28-year-old wife of Sir William Hamilton, the British Envoy to Naples. Emma was a great beauty and a celebrated artists' model, and she was also famous across Europe for performing 'attitudes', which were performances in which she moved quickly from one dramatic pose to another.

Mired in retirement in Norfolk for the previous five years, Nelson had hardly seen a woman since he had returned to sea six months before their meeting, and he was impressed by Lady Hamilton. He wrote to his wife Fanny that Emma was a 'young woman of amiable manners who does honour to the station to which she is raised'.

The second meeting between Nelson and his future mistress was altogether more dramatic. By 1797 the Italian Court, including Emma and her husband, were terrified that Naples would be invaded by French troops. They were hugely relieved in the following year by Nelson's victory over the French fleet at Aboukir, in the 'Battle of the Nile', and they craved the presence of the hero and his fleet in Naples

When Nelson arrived in September, Emma welcomed him in spectacular fashion and he was immediately captivated by her. Emma's husband was also fond of Nelson and, bonded in their determination not to allow Naples to capitulate to the French, the three dubbed themselves the 'Tria juncto in uno'. By the end of 1798, a French invasion seemed inevitable and the 'Tria', along with the Neapolitan royal family, their courtiers, hundreds of foreign travellers and many Neapolitan aristocrats, fled to Sicily.

Nelson, Emma and Sir William soon rented a large house in Palermo together, along with Emma's mother and various English friends. The English press speculated about the close friendship between the 'national hero' - Nelson - and Lady Hamilton. Nelson's wife begged to be allowed to visit him, but he rebuffed her harshly. Emma had encompassed all his attentions.

Emma had never been unfaithful to Sir William since becoming his mistress in 1787 and his wife in 1791. Nelson, too, had been loyal to his wife, in the way that the period defined male fidelity - he had restricted himself to courtesans. But their marriages had not given them the romance and excitement they craved, and both had fallen out of love with their partners. Nelson and Emma shared an emotional temperament and playful sense of humour, as well as boundless energy, ambition and hunger for fame. Their emotions were intensified by the flight from Naples and the

struggle against the French, and they fell profoundly in love. By the beginning of May 1800, Emma was pregnant with Nelson's child.

Battle Plan

Nelson joined the British fleet off Cadiz in late September. His very presence electrified the men under his command, while his new battle plan, explained at his table on HMS *Victory*, was key to decisive combat. If the enemy put to sea Nelson wanted to be able to annihilate them completely, ending the need for Britain to stand on the defensive.

Nelson's arrival unsettled Admiral Villeneuve, who was already being bullied by Napoleon, who wanted his fleet to support an attack on Naples. Thus under pressure Villeneuve, believing Nelson's fleet to be weaker than his own, put to sea on 19 October. In fact his 33 ships of the line faced 27 British vessels.

Nelson anticipated his enemy's every move. At dawn on the 21st the fleets were in visual contact. Nelson's fleet was formed into two columns, for a risky head-on approach that exposed the unarmed bows of his leading ships to the full weight of enemy broadsides. He knew a storm was coming, and he had to engage the enemy quickly.

He was to lead the first column into the attack and destroy the enemy flagship, leaving his opponents, leaderless and confused, to be destroyed by the second column, led by Admiral Cuthbert Collingwood. With the enemy admiral disabled, Nelson knew his skilled captains could wipe out the rest of the opposing fleet in the remaining hours of daylight.

Admiral Pierre de Villenueve

Pierre Charles Jean Baptiste Silvestre de Villeneuve was born into an aristocratic family at Valensoles in Provence in 1763. He joined the French navy at the age of 15 and served as a garde de pavillon under Suffren during the latter's campaign against the British in the Indian Ocean 1782-1783. With the outbreak of the revolution in France, Villeneuve did not follow the lead of many of his contemporaries and resign from the navy. In fact he supported the revolution, dropped the aristocratic "de" from his name and obtained his captaincy. Like Nelson, he was considered a very formidable and inspirational leader.

In 1793 he met Napoleon for the first time and in 1796 was promoted to Rear Admiral. He commanded a squadron in the expedition in which it was planned to invade Ireland and in 1798 was junior flag officer in Brueys' fleet.

1782-1783 Battle in the Indian Ocean

Between February 17, 1782, and September 3, 1782, French Admiral Pierre Andre de Suffren de Saint-Tropez, otherwise known as Bailli de Suffren, and British Vice-Admiral Sir Edward Hughes, commander in chief in the East Indies, engaged in four major battles in the Indian Ocean region: the Battle of Sadras on February 17, the Battle of Providien on April 12, the Battle of Negapatam on July 6 and the Battle of Trincomalee on September 3.

The French attacked British possessions on the Indian coast and in Ceylon as part of the world war spawned by the American Revolution. Although Suffren failed to take any of Hughes' ships, he managed to prevent Hughes from taking any of his own fleet. This alone was a significant improvement in French performance when pitted against the legendary British navy. The fifth and final encounter of the two fleets—the Battle of Cuddalore on April 20, 1783—forced Hughes to leave for Madras, just before Suffren learned of the Treaty of Paris and returned to France.

'England Expects'

As his vessels approached their enemy, Nelson walked around his flagship, talking with the crew - having sent the immortal signal 'England expects that every man will do his duty' to the fleet. All his men cheered this example of courage and confidence that they had but to follow.

The enemy had reversed course during the morning, heading back to Cadiz, leaving their line confused. Now the fleets were off Cape Trafalgar, and the British sailors had time to eat a good meal in preparation for the engagement - although their opponents may not have had such healthy appetites. Nelson waited for Villeneuve to show his flag, so he would know where to strike.

As Victory bore down on the enemy line she had to endure heavy fire from the allied line, without being able to reply. Round shot came smashing through the flimsy bow of the ship, killing and wounding the men on the upper deck. John Scott, Nelson's Public Secretary, was standing on the quarter deck talking with Captain Thomas Hardy, when a shot cut him in two.

Then the steering wheel was smashed, and a double-headed shot scythed down a file of eight marines on the poop. As the battle raged, Nelson and Hardy paced up and down on their chosen ground, the starboard side of the quarterdeck, with splinters flying around them.

When a splinter hit Hardy's shoe, tearing off the buckle, Nelson observed: 'This is too warm work to last for long'. Fifty men had been killed or wounded, and the crew of the Victory had yet to open fire.

Cape Trafalgar

Cape Trafalgar is a headland located in the Province of Cadiz in the south-west region of Span. Its name is of Arabic origin meaning ‘extremity’ or ‘edge’. It lies on the shore of the Atlantic Ocean at the north-west Strait of Gibraltar. The International Hydrographic Organisation defines the Western limit of the strait and the Mediterranean Sea as a line that joins Cape Trafalgar to the north to Cape Spartel to the south. The sea area near the cape is also known as the location of the Battle of Trafalgar.

The most prominent feature on Cape Trafalgar is a 34-metre-high lighthouse built in 1860 called the faro de Cabo Trafalgar.

The Battle

At 12.35pm the concave enemy line allowed the *Victory* to open fire at last, shrouding the ship in smoke. Soon afterwards the *Victory* ran right under the stern of the French flagship, the *Bucentaure*, and fired a double-shotted broadside that made the enemy ship shudder, and killed or wounded over 200 men. Admiral Villeneuve was the only man left standing on the quarter deck.

The *Redoutable* then blocked *Victory's* way through the enemy line, and Nelson was immobilised on a ship fighting three opponents in the middle of the combined fleet - but he had administered the decisive stroke. Villeneuve was trapped on a crippled ship, and the Franco-Spanish centre was reduced to chaos, lacking the leadership to meet the irresistible British.

Nelson, his work done, continued to walk with Hardy, while the captain of the *Redoutable* tried to clear *Victory's* upper deck with musket fire and hand grenades. Then, at about 1.15pm, Nelson was hit by a 0.69in-diameter lead ball, which cut an artery in his lung and lodged in his spine. He was knocked to the deck, and it was clear the wound was mortal. Hardy had his chief carried below, where Surgeon William Beatty was hard at work on the mounting list of casualties.

Meantime the battle raged, with the faster and more effective British gunnery steadily wearing down the enemy. Over the next three hours the Franco-Spanish force would collapse. Nelson's attack had broken all the rules of tactics, treating a fleet waiting for a fight like one running away, substituting speed for mass, precision for weight, and accepting impossible odds.

The Bucentaure

The Bucentaure was the flagship of Vice-Admiral Latouche Treville's French Navy. She was an 80-gun ship built by Arsenal de Toulon and laid down in 1802.

At the Battle of Trafalgar, on 21 October 1805, she was commanded by Captain Jean-Jacques Magendie. Admiral Nelson's HMS *Victory*, leading the weather column of the British fleet, broke the French line just astern of *Bucentaure* and just ahead of *Redoutable*.

In the days that followed the conclusion of the Battle of Trafalgar, *Bucentaure'*s surrendered crew rose up against the British prize crew, and recaptured the ship. However, she was wrecked in the gale-force storm of 23 October 1805

Nelson's death

As Nelson lay wounded, the battle with the *Redoutable* reached a crescendo. The French repeatedly tried to board the *Victory*, only to be driven back by heavy fire, and at 1.30pm the captain of the *Redoutable* surrendered.

At 2.15pm Villeneuve surrendered. The genius of his opponent, the power of the Royal Navy and the failure of his lead squadron to come to his aid had doomed his brave effort. He lived to return to France, only to be murdered by Napoleon.

By 2.30pm Hardy was able to go below, to report to Nelson that 12 or 14 of the enemy were taken, and no British ship had surrendered. That last answer betrayed Nelson's anxiety about the outcome of the battle. Hardy, however, could not linger, the lead enemy squadron was belatedly trying to join the battle, only to be bettered by Edward Codrington's brilliantly handled *Orion*, the *Minotaur* and the *Spartiate*. Hardy went back on deck and signalled the ships nearby to support the flagship.

Hardy visited Nelson again at 3.30pm to confirm a glorious victory, but could not satisfy Nelson's determination to have 20 prizes. 'Anchor, Hardy, Anchor!' the dying man demanded, as the rising sea reminded him of his weather forecast.

Hardy knelt and kissed him, as Nelson struggled to breathe and kept repeating his motto: 'Thank God I have done my duty.' Unable to endure his grief at his leader's plight, Hardy went back to the upper deck, burying his feelings in the fighting. Nelson died shortly before 4.30pm, as the battle died down. Nineteen enemy ships had been taken.

'Kiss Me Hardy'

The Victorians, with their obsessive need for pure, spotless heroes, tried hard to eliminate Nelson's beloved mistress Emma Hamilton from the story of his life - even going so far as to suppress passionate passages in his letters to her, which were considered too 'warm' to be publicly acceptable.

They took a similar approach to Nelson's famous request for a kiss from his devoted Flag Captain Thomas Hardy, as he lay dying in the sick bay of the *Victory*. The Victorians, unable to accept the idea of two fighting men kissing each other, therefore decided that Nelson must have suddenly started speaking Turkish - 'Kismet [fate] Hardy' - and that Hardy had misheard him.

Nowadays we are more realistic about our heroes and can accept that it is possible for someone to be heroic without being unrealistically virtuous. So Emma Hamilton has been allowed to take her rightful place at Nelson's side in the story, and meticulous research has restored the censored passages in his letters - revealing him, in the process, as an eloquently romantic writer.

Research, too, has sunk the 'Kismet' theory with all hands. No fewer than three eyewitness accounts of Nelson's death have survived, and all of them mention the kiss. Indeed we now know that the kiss was being talked about in the British fleet within days of the battle - and not with sniggers but with tears. Men who had just endured the hell of a close-quarters battle, and the ferocious storm that followed it, perfectly understood the request for a final gesture of tenderness by the man who had led them by tenderness and affection.

Cost of Victory

At the start of the battle, when the first British ships arrived, they were initially fighting a far greater number of enemy ships. They won the day because of their speed and flexibility, and by the time they were weakening, a later wave of vessels was in place to administer the *coup de grace*.

In fact the battle was won while the enemy had far more ships in the fight than the British. The real triumph was not of 27 ships against 33, but of 12 against 22. British casualties tell the story - 12 ships fought the early and decisive phase of the battle, suffering some 1200 deaths and injuries.

In total Some 1,700 British were killed or wounded, with 6,000 enemy casualties and nearly 20,000 prisoners. Many of those lives, as well as Villeneuve's flagship, were lost in the storm that followed the battle.

The following day, Nelson's oldest friend, Admiral Collingwood, opened his wonderful Order of Thanks for the men of the fleet with the following lines:

“The ever to be lamented death of Vice Admiral Lord Viscount Nelson, Duke of Bronte, the Commander in Chief, who fell in the action of the 21st, in the arms of Victory, covered with glory, whose memory will be ever dear to the British Navy and the British Nation; whose zeal for the honour of his King, and for the interests of his Country, will ever be held up as a shining example for a British seaman.”

This powerful document only heightened the emotional impact of the news across the nation - for Britons the triumph over Napoleon was cancelled out by the loss of Nelson. The loss, however, provided a national hero to help enhance the newly formed British identity. Trafalgar, as the battle was named by George III, had crushed the naval power of a deadly enemy, and - although they had fought like heroes - the Spanish and French had been annihilated.

Trafalgar was the coda to Nelson's achievement. He had destroyed Napoleon's maritime strategy and invasion plans when he pursued Villeneuve to the West Indies and back. This had set the limit to Napoleon's empire, and plotted the course of his downfall.

Other British admirals could have won at Trafalgar, but only Nelson could have settled the command of the sea for a century. Trafalgar was the product of one man's obsessive genius and unequalled commitment to his country.

Appendix B: Working Memory Text (Study 3 and 4)

Working Memory: A Background

The term 'working memory' was coined in 1960 by Miller, Galanter and Pribram in their classic book '*Plans and the Structure of Behaviour*' and adopted as the title for a multicomponent model by Baddeley and Hitch. The concept of working memory evolved from that of short-term memory, the temporary storage of small amounts of material over brief periods of time. It became a topic of major interest during the 1960s, linked to an information-processing approach to psychology, in which the digital computer served as a theoretical basis for the development of psychological theories. This approach became known as cognitive psychology. A very fruitful development stemmed from applying the concepts and methods of cognitive psychology to patients with brain impairment, an approach termed cognitive neuropsychology. While most brain-damaged patients typically suffer from a number of deficits, cases occasionally occur in which a single isolated cognitive function is impaired, while other functions are preserved, allowing theories to be tested.

Following these developments, Baddeley and Hitch (1974) proposed one framework of working memory comprising multiple specialised subcomponents of cognition. Their multidimensional framework comprises a central executive controlling mechanism and two subsidiary or "slave" systems, called the phonological loop, and the visuospatial sketchpad, which are specialised for the processing and temporary maintenance within a particular domain.

Patients with Brain Impairment

A very influential case in the development and history of working memory was that of Henry Gustav Molaison (known for years as H.M. in the literature to protect his privacy). HM developed severe amnesia at age 27 after undergoing brain surgery as a form of treatment for the epilepsy he had suffered from since childhood. His surgery involved the removal of large parts of the hippocampus on both sides of his brain. The result was that he was almost entirely unable to store any new information in long-term memory (there were some exceptions – for example, after 1963 he was aware that a US president had been assassinated in Dallas). He could, however, perform normally on short-term memory tasks such as hearing and repeating back a telephone number. These deficits

came as a surprise to many experts of the day because many of them believed that memory was distributed throughout the cerebral cortex. Such cases provide support for a multicomponent theory when evaluating the working memory model.

Similarly, The KF Case Study also helped in the development of working memory models. Patient KF suffered brain damage from a motorcycle accident that damaged his short-term memory. KF's impairment was mainly for verbal information – his memory for visual information was largely unaffected. This showed that there are separate short-term memory components for visual information and verbal information. Other cases of amnesic patients helped in the development of the episodic buffer component of working memory proposed later by Baddeley (2000).

Episodic Buffer

The episodic buffer is the fourth main component within the working memory model and is theorized to integrate the phonological loop and visuospatial sketchpad functions with a sense of time, so that things occur in a continuing sequence, like a story from a book or movie. This theory is used to explain why memories can be experienced as a coordinated sequence of events rather than as discrete segments. The episodic buffer acts as a 'backup' store which communicates with both long-term memory and the components of working memory.

One of the main motivations for introducing this component was the observation that in cases of individuals with brain impairments, some (in particular, highly intelligent) patients with amnesia, who presumably have no ability to encode new information in long-term memory, nevertheless have good short-term recall of stories, recalling much more information than could be held in the phonological loop.

The Central Executive

The central executive is responsible for monitoring and coordinating the operation of the slave systems of the working memory model (the visuospatial sketchpad and phonological loop), and helps integrate them with long term memory. It determines which information is attended to and which parts of the working memory to send that information to be dealt with. The precise function

of the central executive was unspecified within the original framework of the multicomponent model. Cowan's (1999) embedded-processes model aimed to expand on this.

Baddeley suggests that the central executive acts more like a system which controls attentional processes rather than as a memory store. Baddeley uses the metaphor of a company boss to describe the way in which the central executive operates. The company boss makes decisions about which issues deserve attention and which should be ignored. They also select strategies for dealing with problems, but like any person in the company, the boss can only do a limited number of things at the same time. The boss of a company will collect information from a number of different sources.

If we continue applying this metaphor, then we can see the central executive in working memory integrating (i.e., combining) information from two assistants (the phonological loop and the visuospatial sketchpad) and also drawing on information held in a large database (long-term memory). Baddeley (2000) later expanded on how the slave functions are integrated by adding another component to the model – the episodic buffer.

The Phonological Loop

The phonological loop is the part of working memory that deals with spoken and written material. It consists of two parts. Firstly, the phonological store (linked to speech perception) acts as an inner ear and holds information in a speech-based form (i.e., spoken words) for 1-2 seconds. Spoken words enter the store directly. Written words must first be converted into an articulatory (spoken) code before they can enter the phonological store. Secondly, the articulatory control process (linked to speech production) acts like an inner voice rehearsing information from the phonological store. It circulates information round and round like a tape loop. This is how we remember a telephone number we have just heard. As long as we keep repeating it, we can retain the information in working memory. The articulatory control process also converts written material into an articulatory code and transfers it to the phonological store. The central executive is thought to be responsible for monitoring information between the phonological loop and other slave systems within the

working memory model. One way of testing the phonological loop is through the use of the classic verbal digit span task, a subtest of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008).

Testing the Phonological Loop

One way of testing the phonological loop is by the use of the digit span subtest of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008). This test makes up part of a larger series of tests called the Wechsler test battery and is a widely-used measure of verbal working memory performance. In this task, participants must attempt to immediately and accurately verbally recall a series of digits spoken by the experimenter which increase in length across three conditions: forwards (condition 1); backwards (condition 2); and in numerical order (condition 3). Scores are taken based on 'maximum verbal span' (the maximum number of digits in a sequence successfully recalled), and 'raw score' (the total number of sequences correctly recalled under the appropriate instruction/condition). Variations on this task can include the use of names of objects or animals in place of digits. In this variation, participants must repeat the sequences in forwards and backwards order, with an additional sequence requiring the verbalising of the objects or animals into size order. This ordering sequence is the most cognitively demanding, as it requires participants to hold verbal information, manipulate it into a different order, and then verbalise back. This task provides support for a multicomponent system when evaluating the working memory model.

The Visuo-Spatial Sketchpad

The visuospatial sketchpad deals with visual and spatial information. It is likely that the visuospatial sketchpad plays an important role in helping us keep track of where we are in relation to other objects as we move through our environment (Baddeley, 1997). As we move around, our position in relation to objects is constantly changing and it is important that we can update this information. For example, being aware of where we are in relation to desks, chairs and tables when we are walking around a classroom means that we don't bump into things too often. The sketchpad is responsible for manipulating visual and spatial information held in long-term memory, such as the spatial layout of your house. As a result, we can test visuospatial memory by measuring one's ability to manipulate visual information.

Evidence suggests that working memory uses two different systems for dealing with visual and verbal information. A visual processing task and a verbal processing task can be performed at the same time. It is more difficult to perform two visual tasks at the same time because they interfere with each other and performance is reduced. The same applies to performing two verbal tasks at the same time. This effect can be seen in the dual-task experiment. This supports the view that the phonological loop and the sketchpad are separate systems within working memory, both of which are integrated by the episodic buffer.

Testing the Visuospatial Sketchpad

An example of the ability to manipulate visual information in working memory comes from a famous mental rotation task devised by Shepard and Metzler (1971). They presented people with pairs of drawings that could be perceived as three-dimensional constructions made of cubes. The participant's task was to see whether the shape on the right was identical to the one on the left; some were, and some were not. Even when the shapes were identical, the one on the right was sometimes drawn as if it had been rotated. Shepard and Metzler found that people were accurate in judging whether the pairs of shapes that were the same or different but took longer to decide when the right-handed shape was rotated. They concluded that participants attempted to form an image of one of the drawings in their heads and rotated it until it was aligned with the other one. If their rotated image matched with the drawing, they recognised them as having the same shape. If they did not, they recognised them as being different. Another example comes from the Corsi blocks test, in which participants must watch the order in which a sequence of blocks is tapped, and then either repeat the sequence, or manipulate the information in their memory so that they are able to recall the sequence in reverse order. These tasks provide support for a multicomponent system when evaluating the working memory model.

Long-Term Memory

One of the earliest and most influential distinctions of long-term memory was proposed by Tulving (1972). He proposed a distinction between episodic, semantic and procedural memory. Procedural memory is a part of the long-term memory is responsible for knowing how to do things, i.e. memory

of motor skills. Semantic memory is a part of the long-term memory responsible for storing information about the world. This includes knowledge about the meaning of words, as well as general knowledge. Episodic memory is a part of the long-term memory responsible for storing information about events (i.e. episodes) that we have experienced in our lives. Cowan (1999) elaborated on the link between attention and long-term memory in the embedded processes model.

Cohen and Squire (1980) also drew a distinction between declarative knowledge and procedural knowledge. Procedural knowledge involves "knowing how" to do things. It included skills, such as "knowing how" to playing the piano, ride a bike; tie your shoes and other motor skills. It does not involve conscious thought (i.e. unconscious, automatic). For example, we brush our teeth with little or no awareness of the skills involved. Whereas, declarative knowledge involves "knowing that", for example London is the capital of England, zebras are animals, your mum's birthday etc. Recalling information from declarative memory involves some degree of conscious effort – information is consciously brought to mind and "declared".

Embedded Processes Model

Cowan's (1999) embedded-processes model of working memory filled the gap in knowledge about the function of the central executive within Baddeley's (1974) multicomponent working memory model. It describes a single attentional mechanism that is able to (re)activate any long-term memory trace irrespective of its content. He proposed the following five principles, which emphasize links between memory and attention:

(1) Working memory information comes from hierarchically arranged faculties comprising: (a) long-term memory, (b) the subset of long-term memory that is currently activated, and (c) the subset of activated memory that is in the focus of attention and awareness.

(2) Different processing limits apply to different faculties. The focus of attention is basically capacity limited, whereas activation is time limited. The various limits are especially important under nonoptimal conditions, such as interference between items with similar features.

(3) The focus of attention is controlled conjointly by voluntary processes (a central executive system) and involuntary processes (the attentional orienting system).

(4) Stimuli with physical features that have remained relatively unchanged over time and are of no key importance to the individual still activate some features in memory, but they do not elicit awareness.

(5) Awareness influences processing. In perception it increases the number of features encoded, and in memory it allows new episodic representations to be available for explicit recall.

The Dual-Task Experiment

The working memory model makes the following two predictions:

1. If two tasks make use of the same component (of working memory), they cannot be performed successfully together.

2. If two tasks make use of different components, it should be possible to perform them as well as together as separately.

Logic, Zucco, and Baddeley (1990) investigated the effects of concurrent tasks on two components of working memory. Participants completed both a visuospatial (visual span) and verbal (letter span) working memory task. They predicted that if participants are performing at the limits of their working memory capacity on the primary visual-span or letter-span task, then the addition of a concurrent secondary task that also occupies these domains should result in a drop in performance. They found that visual span was significantly impaired by a concurrent imagery task but was only slightly impaired by a concurrent mental arithmetic task. The converse was true for letter span performance. This provides evidence for a multicomponent working memory system, with semi-independent specialised mechanisms at work.

Similarly, Baddeley (1992) conducted a dual-task experiment involving memory of complex chess positions. They found that there was no disruption in ability to remember positions from a concurrent verbal task, but clear impairment from tasks occupying the visuospatial sketchpad or the central executive, again demonstrating the separability of the memory systems responsible for learning.

Evaluating the Working Memory Model

Since its conception, the working memory model has been both influential and controversial. Lieberman (1980) criticizes the working memory model as the visuospatial sketchpad implies that all spatial information was first visual (they are linked). However, Lieberman points out that blind people have excellent spatial awareness, although they have never had any visual information. Lieberman argues that the visuospatial sketchpad should be separated into two different components: one for visual information and one for spatial. Also, there is little direct evidence for how the central executive works and what it does. The capacity of the central executive has never been directly measured. Furthermore, the model does not explain changes in processing ability that occur as the result of practice or time.

However, a strength of the model is that researchers generally agree that short-term memory is made up of a number of components or subsystems. Evidence from patients with brain impairments provide support for a multicomponent model of working memory, as well as studies such as Baddeley and Hitch's (1976) dual-task experiment which show that tasks can measure separate components of working memory.

Appendix C: Reading Comprehension Test (Study 1)

READING TASK MCQs

PROJECT TITLE: LEARNING THROUGH HYPERTEXT: HOW METACOGNITIVE EXPERIENCE AND WORKING MEMORY CAPACITY ARE RELATED TO TEST PERFORMANCE

Researcher: Marc Edwards

Academic Supervisors: Dr Judith Wylie, Dr Aidan Feeney

Please answer all questions provided honestly and carefully. You will be asked a series of questions related to the text you have just read. For the multiple-choice questions, circle the letter of the correct answer. After each question please indicate on a 6-point scale how confident you are in your response: 0 = very uncertain; 6 = very certain.

1. **In which year did the Battle of Trafalgar take place?**

   a) **1805**
   b) **1800**
   c) **1795**
   d) **1810**

2. **Who won the Battle of Trafalgar?**

   a) **The French**
   b) **The Spanish**
   c) **The British**
   d) **The Italians**

3. **What was the temporary truce between Britain and France which broke down in 1803 called?**

   a) **The Treaty of Versailles**
   b) **The Peace of Amiens**
   c) **The Treaty of Paris**
   d) **The Peace of Trafalgar**

4. **Where was Admiral Villeneuve's fleet waiting to attack the British?**

   a) **Cape Trafalgar**
   b) **Cadiz**

c) **Cape Vincent**
d) **Naples**

5. **Which of the following 4 ships was *not* mentioned in the text?**

a) **Agamemnon**
b) **Redoutable**
c) **HMS Victory**
d) **HMS Implacable**

6. **How many times was Admiral Lord Nelson married?**

a) **0**
b) **1**
c) **2**
d) **3**

7. **Which European city was Napoleon also thinking about prior to the battle of Trafalgar?**

a) **Paris**
b) **Rome**
c) **Naples**
d) **Utrecht**

8. **With whom did Nelson have an affair?**

a) **Thomas Hardy**
b) **Lady Hamilton**
c) **Horatia**
d) **Lady Tremaine**

9. **According to the text, for how long did their liaison last?**

a) **10 years**
b) **2 years**
c) **8 years**
d) **6 years**

10. **On which ship did Nelson explain his battle plan for the Battle of Trafalgar?**

a) **HMS Victory**
b) **The Bucentaure**
c) **The Agememnon**
d) **HMS Berwick**

11. **How many vessels did Villeneuve have with which to face the British fleet?**

a) 27
b) 33
c) 23
d) 43

12. Who led the second column for the British?

a) Admiral Lord Nelson
b) Thomas Hardy
c) Admiral Cuthbert Collingwood
d) Sir William Hamilton

13. Which of the following signals indicated to Nelson where to strike?

a) The French fleet began firing
b) Villeneuve's ship dropped its anchor
c) Villeneuve appeared on the deck of his ship
d) Villeneuve showed his flag

14. Where did a loose splinter strike Thomas Hardy during the opening exchanges between Victory and the enemy line?

a) His eye
b) His arm
c) His shoe
d) His belt

15. Approximately how many men were wounded in the early stages of the battle (after HMS Victory began to fire)?

a) 200
b) 100
c) 1000
d) 500

16. What is the most prominent feature of Cape Trafalgar?

a) A church
b) A lighthouse
c) A monument
d) A tree

17. Who commanded the French flagship, the Bucentaure, at the Battle of Trafalgar?

a) Admiral Villeneuve
b) Vice-Admiral Latouche Treville

c) **Captain Jean-Jaques Magendie**
d) **Arsenal de Toulon**

18. **In which part of the body was Nelson injured at the Battle of Trafalgar?**

a) **An eye**
b) **An arm**
c) **A leg**
d) **His spine**

19. **What was Nelson's motto, murmured on his death-bed?**

a) **"Thank God I have done my duty"**
b) **"Anchor, Hardy. Anchor!"**
c) **"This is too warm work to last for long."**
d) **"We will fight them on the beaches."**

20. **What was the fate of Villenueve?**

a) **He died during the battle**
b) **He was murdered by Napoleon**
c) **He was demoted**
d) **There is no record**

21. **Who was the reigning monarch at the time of the battle of Trafalgar?**

a) **Queen Victoria**
b) **Queen Elizabeth I**
c) **King George III**
d) **King Henry V**

22. **In total, approximately how many British were killed or wounded?**

a) **1700**
b) **1200**
c) **3000**
d) **2500**

23. **Who gave the 'Order of Thanks' to the men of the fleet following the battle?**

a) **Napoleon**
b) **The King**
c) **Admiral Collingwood**
d) **Edward Codrington**

24. **What signal made Nelson know where to strike?**

a) **Napoleon appeared on deck**
b) **Villeneuve showed his flag**
c) **Thomas Hardy yelled out**
d) **A flare was set off**

25. **What evidence is there that Bonaparte respected Nelson and considered him a hero?**

26. **Name 2 ways in which the Victorians attempted to change the history of Nelson so that he remained a "pure, spotless hero".**

27. **What evidence is there in the text that Nelson was a great Naval Commander?**

28. **According to the text, what were the reasons behind Nelson's affair?**

Appendix D: Reading Comprehension Test (Study 2)

READING TASK MCQs

PROJECT TITLE: LEARNING THROUGH HYPERTEXT: HOW METACOGNITIVE EXPERIENCE AND WORKING MEMORY CAPACITY ARE RELATED TO TEST PERFORMANCE

Researcher: Marc Edwards

Academic Supervisors: Dr Judith Wylie, Dr Aidan Feeney

Please answer all questions provided honestly and carefully. You will be asked a series of questions related to the text you have just read. For the multiple-choice questions, circle the letter of the correct answer. After each question please indicate on the scale, how certain you are that you answered correctly as a percentage: 0% = certain you are wrong, 100% = certain you are correct.

1. **In which year did the Battle of Trafalgar take place?**

    e) **1805**

    f) **1800**

    g) **1795**

    h) **1810**

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

2. **Who won the Battle of Trafalgar?**

    e) **The French**

    f) **The Spanish**

    g) **The British**

    h) **The Italians**

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

3. **What was the temporary truce between Britain and France which broke down in 1803 called?**

    e) **The Treaty of Versailles**

f) The Peace of Amiens

g) The Treaty of Paris

h) The Peace of Trafalgar

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

4. Where was Admiral Villeneuve's fleet waiting to attack the British?

e) Cape Trafalgar

f) Cadiz

g) Cape Vincent

h) Naples

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

5. How many times was Admiral Lord Nelson married?

e) 0

f) 1

g) 2

h) 3

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

6. Which European city was Napoleon also thinking about prior to the battle of Trafalgar?

e) Paris

f) Rome

g) Naples

h) Utrecht

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

7. With whom did Nelson have an affair?

e) Thomas Hardy

f) Lady Hamilton

g) Horatia

h) Lady Tremaine

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

8. According to the text, for how long did their liaison last?

e) 10 years

f) 2 years

g) 8 years

h) 6 years

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

9. On which ship did Nelson explain his battle plan for the Battle of Trafalgar?

e) HMS Victory

f) The Bucentaure

g) The Agememnon

h) HMS Berwick

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

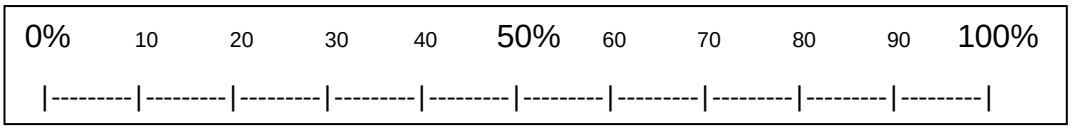
10. How many vessels did Villeneuve have with which to face the British fleet?

e) 27

f) 33

g) 23

h) 43



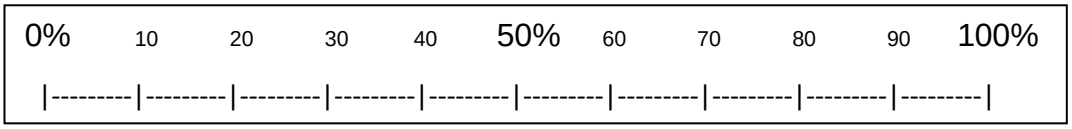
11. Who led the second column for the British?

e) Admiral Lord Nelson

f) Thomas Hardy

g) Admiral Cuthbert Collingwood

h) Sir William Hamilton



12. Which of the following signals indicated to Nelson where to strike?

e) The French fleet began firing

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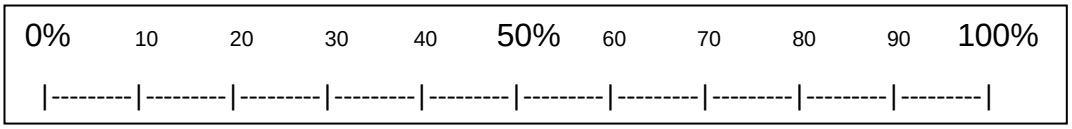
h) Villeneuve showed his flag



13. Where did a loose splinter strike Thomas Hardy during the opening exchanges between Victory and the enemy line?

e) His eye

f) His arm

g) His shoe

h) His belt

0% 10 20 30 40 50% 60 70 80 90 100%

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14. Approximately how many men were wounded in the early stages of the battle (after HMS Victory began to fire)?

e) 200

f) 100

g) 1000

h) 500

0% 10 20 30 40 50% 60 70 80 90 100%

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15. What is the most prominent feature of Cape Trafalgar?

e) A church

f) A lighthouse

g) A monument

h) A tree

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

16. In which part of the body was Nelson injured at the Battle of Trafalgar?

e) An eye

f) An arm

g) A leg

h) His spine

0% 10 20 30 40 50% 60 70 80 90 100%

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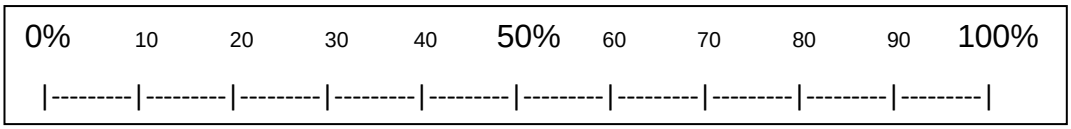
17. What was Nelson's motto, murmured on his death-bed?

e) **“Thank God I have done my duty”**

f) **“Anchor, Hardy. Anchor!”**

g) **“This is too warm work to last for long.”**

h) **“We will fight them on the beaches.”**



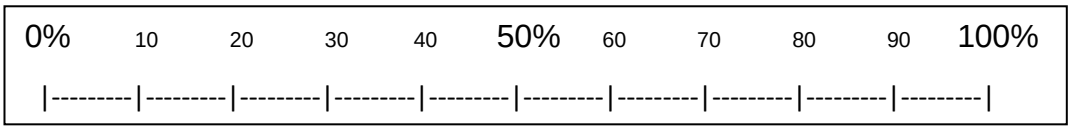
18. What was the fate of Villenueve?

e) **He died during the battle**

f) **He was murdered by Napoleon**

g) **He was demoted**

h) **There is no record**



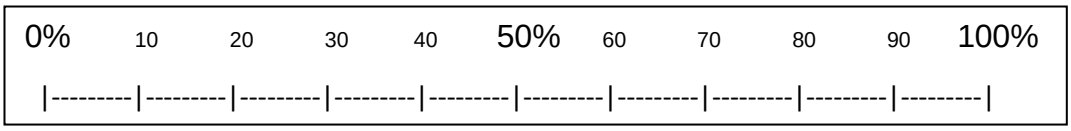
19. Who was the reigning monarch at the time of the battle of Trafalgar?

e) **Queen Victoria**

f) **Queen Elizabeth I**

g) **King George III**

h) **King Henry V**



20. In total, approximately how many British were killed or wounded?

e) **1700**

f) **1200**

g) **3000**

h) **2500**

0% 10 20 30 40 50% 60 70 80 90 100%

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21. Who gave the 'Order of Thanks' to the men of the fleet following the battle?

e) Napoleon

f) The King

g) Admiral Collingwood

h) Edward Codrington

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

22. In which ways can Nelson and Villeneuve be considered similar?

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

23. What evidence is there that Bonaparte respected Nelson and considered him a hero?

0% 10 20 30 40 50% 60 70 80 90 100%

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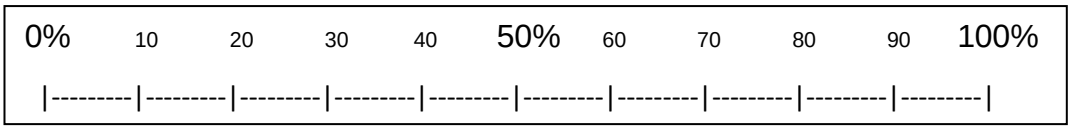
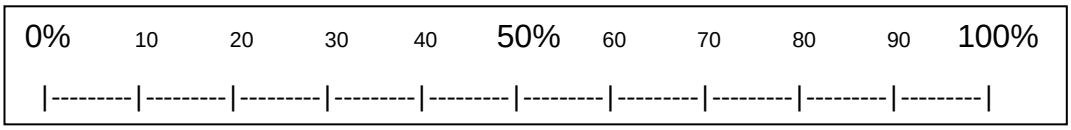
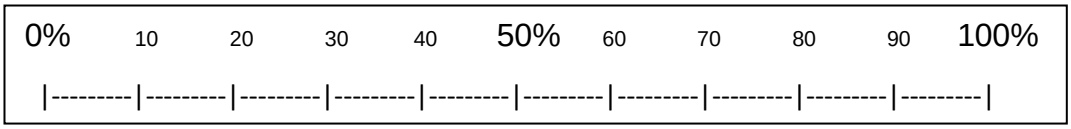
24. Name 2 ways in which the Victorians attempted to change the history of Nelson so that he remained a "pure, spotless hero".



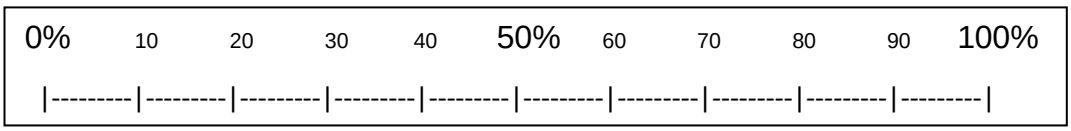
25. What evidence is there in the text that Nelson was a great Naval Commander?



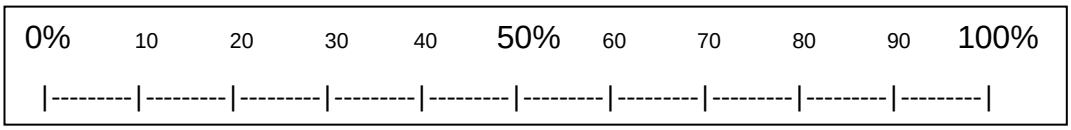
26. According to the text, what were the reasons behind Nelson's affair?



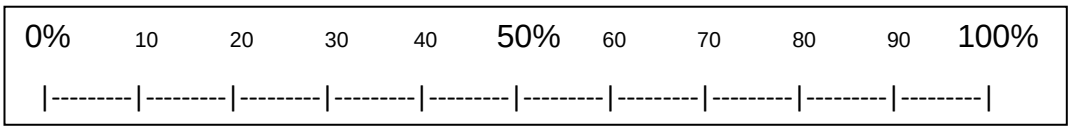
27. Name 2 ships, other than *HMS Victory* and the *Bucentaure*, mentioned in the text.



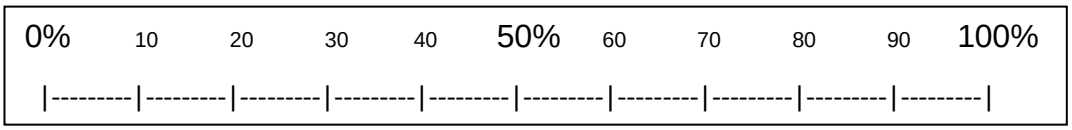
28. Name 3 important *times* during the Battle of Trafalgar.



29. Name 4 key events that happened during the Battle of Trafalgar.



30. Name 2 events that happened in the days after the conclusion of the Battle of Trafalgar.



Appendix E: Reading Comprehension Test (Studies 3 and 4)

READING TASK MCQs

Please answer all questions provided honestly and carefully. For the multiple-choice questions, circle the letter of the correct answer. After each question please indicate on the scale, how certain you are that you answered correctly as a percentage: 0% = certain you are incorrect, 100% = certain you are correct.

1. **Who first proposed a multicomponent theory of working memory?**

   i) **Miller, Galanter, and Pribram (1960)**

   j) **Nelson Cowan (1999)**

   k) **Baddeley and Hitch (1974)**

   l) **Tulving (1972)**

0% 10 20 30 40 50% 60 70 80 90 100%

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2. **What effect did the removal of parts of the hippocampus have on patient H.M?**

   a) **He was unable to store any new information in long-term memory**

   b) **He was unable to store any new information in short-term memory**

   c) **It had no effect – memory is related to the cerebral cortex**

   d) **He was unable to hear and repeat back a telephone number**

0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

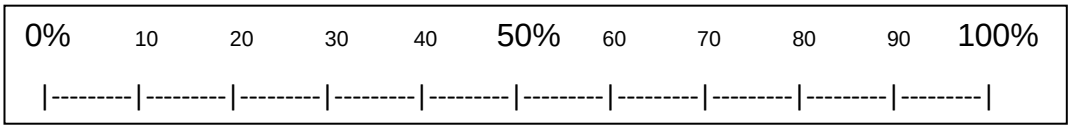
3. **What function is thought to be served by the episodic buffer?**

a) It integrates short-term and long-term memory

b) It integrates both the phonological loop and visuospatial sketchpad with a sense of time

c) It integrates only the phonological loop with a sense of time

d) It integrates only the visuospatial sketchpad with a sense of time



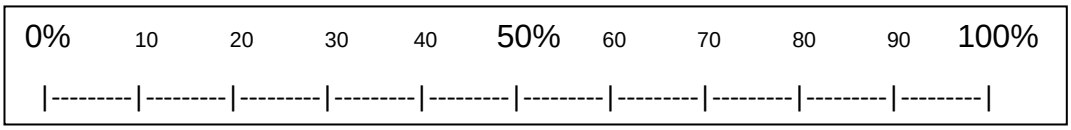
4. What is the central executive responsible for?

a) Working as a memory store for visual and verbal information

b) Monitoring and coordinating the operation of the long-term memory system

c) Monitoring and coordinating the operation of visuospatial sketchpad and phonological loop

d) All of the above



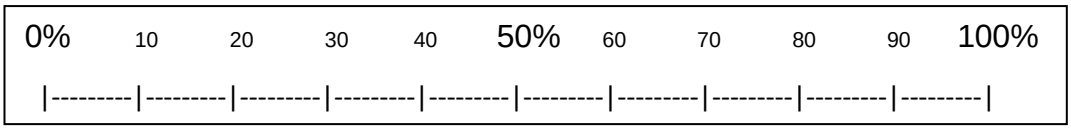
5. Which of these is NOT a way of testing the phonological loop?

a) Verbally recalling a sequence of digits in backwards order

b) Repeating back the names of a series of animals

c) Memorising and recalling a phone number

d) Recalling how many rooms there are in your house



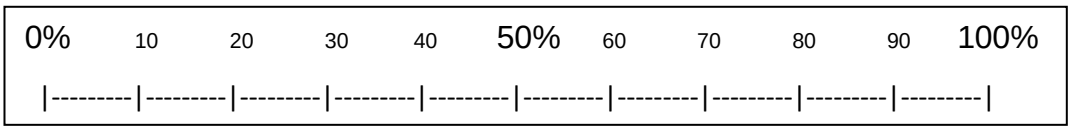
6. Which of the following is a prediction of the dual-task experiment?

a) If two visual tasks are performed together, there will be a drop in performance

b) If a visual and a verbal task are performed together, there will be a drop in performance

c) If two verbal tasks are performed together, there will not be a drop in performance

d) If two visual tasks are performed together, there will not be a drop in performance



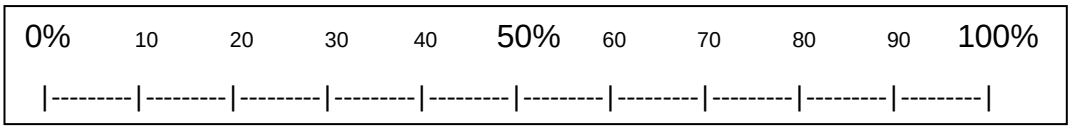
7. Which of the following was a finding of the original mental rotation task?

a) Participants took the same amount of time to decide whether the pairs of shapes were the same or different when the right-handed shape was rotated

b) Participants took longer to decide whether the pairs of shapes were the same or different when the right-handed shape was identical

c) Participants took longer to decide whether the pairs of shapes were the same or different when the right-handed shape was rotated

d) None of the above



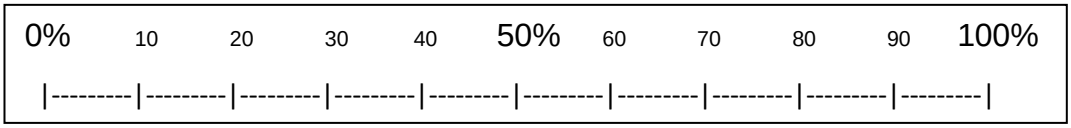
8. Which of these is NOT a main principle of the embedded processes model?

a) The focus of attention is controlled by voluntary and involuntary processes

b) Different processing limits apply to different faculties

c) Working memory information comes from hierarchically arranged faculties

d) Stimuli with physical features that are of no key importance to the individual do not activate any features in memory



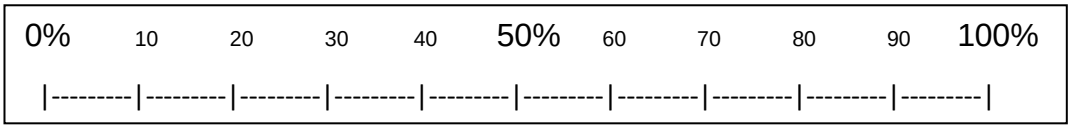
9. What can be considered a weakness of the working memory model?

a) There is little direct evidence for how the central executive works and what it does

b) Evidence from patients with brain impairments

c) Findings of the dual-task experiment

d) Researchers generally disagree that short-term memory is made up of several components



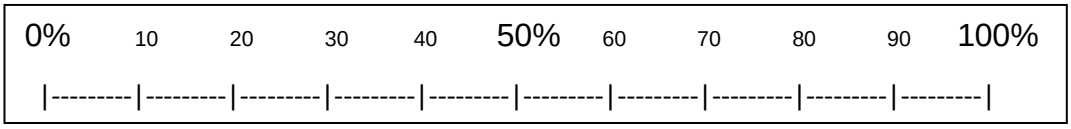
10. Which of these statements is true of the phonological loop?

a) Spoken words must first be converted into articulatory code before entering the phonological store

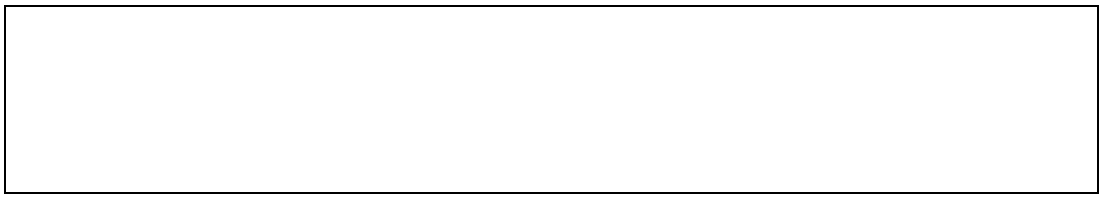
b) Written words must first be converted into articulatory code before entering the phonological store

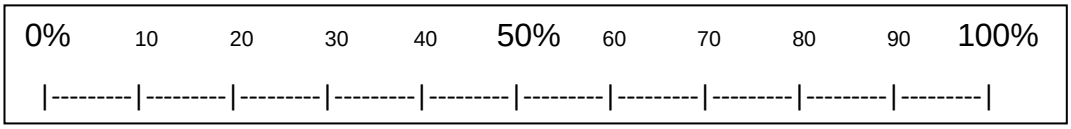
c) Written words enter the phonological store directly

d) The phonological store holds information in speech-based form for 1-2 minutes



11. What evidence is there in support of a multicomponent model of working memory? Think of at least two things from the text.





12. Name one piece of information that might be stored in the visuospatial sketchpad (different from what has been mentioned in the text).



0% 10 20 30 40 50% 60 70 80 90 100%

|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

13. Which statement best describes how the original working memory model and embedded processes model differ?

a) The embedded processes model describes the central executive as having several attentional mechanisms able to reactivate any long-term memory trace, whereas it is unspecified in the original working memory model

b) The embedded processes model describes the central executive as a single attentional mechanism able to reactivate any long-term memory trace, whereas it is unspecified in the original working memory model

c) The original working memory model views the central executive as a memory store, whereas the embedded processes model does not

d) The original working memory model does not view the central executive as a memory store, whereas the embedded processes model does

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14. Pick the correct chronological order of events.

a) Multicomponent working memory model > Mental rotation task devised > Episodic buffer added > embedded processes model

b) Mental rotation task devised > Multicomponent working memory model > Embedded processes model > Episodic buffer added

c) Mental rotation task devised > Dual-task experiment > Multicomponent working memory model > embedded processes model

d) Embedded processes model > Mental rotation task devised > Dual-task experiment > episodic buffer added

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15. **Neuroimaging methods such as fMRI and CT scanning allow scientists to view the structure of, and activity in, parts of the brain. How might this method provide support for a multicomponent model of working memory?**

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16. **Complete the sentence: 'An individual with an impairment to working memory might be unable to…'**

a) '…manipulate stored information.'

b) '…judge whether pairs of shapes are the same or rotated.'

c) '…recall a sequence of numbers in numerical order.'

d) All of the above

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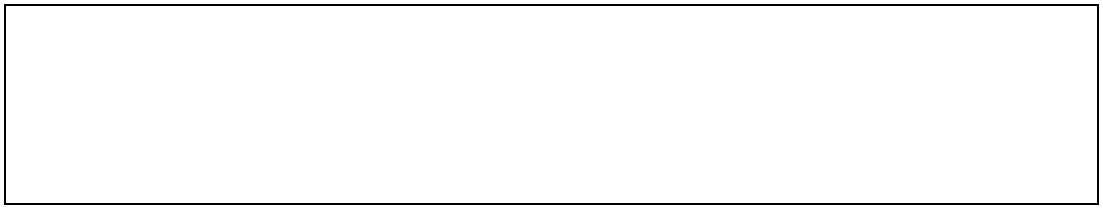
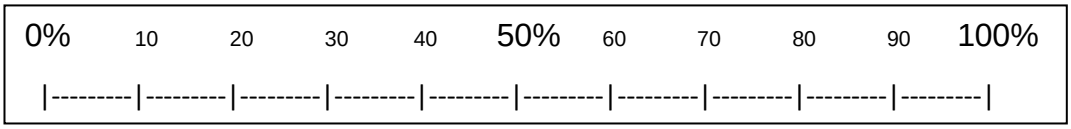
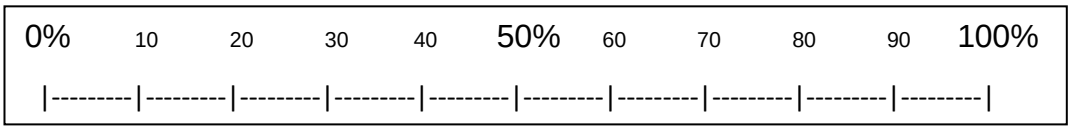
17. **“Since its conception, the working memory model has been both influential and controversial.” Why might the working memory model be considered controversial?**





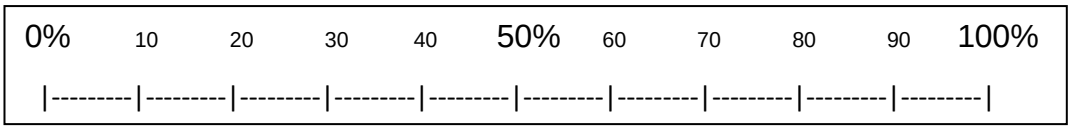
18. **Which of the components of working memory do you think might be considered as the most important? Why?**





19. **Name one piece of information that might be stored in the phonological loop (different from what has been mentioned in the text).**





20. "The original working memory model was comprehensive and could not be improved." Do you agree with this statement? Why?

