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공학석사 학위논문

**Comparison of
Cognitive Workload Differences
Across Paper, Computer, and Tablet
for Short Passage Reading Tasks**

짧은 글 읽기의 매체 별 (종이, 컴퓨터, 태블릿)
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2018 년 8 월

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이 논문을 공학석사 학위논문으로 제출함

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Comparison of Cognitive Workload Differences Across Paper, Computer, and Tablet for Short Passage Reading Tasks

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Abstract

Comparison of Cognitive Workload Differences Across Paper, Computer, and Tablet for Short Passage Reading Tasks

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As portable technology has become prevalent in our daily lives, people's reading activity, especially their means of access, has changed with the variety of reading media available. People can selectively choose reading media and utilize a mixture of print and digital media based on their preferences and purposes. However, as digital reading is a natural activity for younger people, there has been growing concern that reading on digital media could profoundly affect people's abilities, preferences, and attitudes towards reading. Taking this into account, researchers have performed comparison studies of print and digital readings with various age groups to investigate differences in reading experience and possible effects on reading abilities, such as reading time and reading comprehension. Although multiple studies have demonstrated phenomenological differences between print and digital readings, these studies have shown inconsistent findings; nevertheless, differentiating between the reading effects of print and digital media results in a wide variety of outcomes.

To further explore differences of reading experience between print and digital reading, the present study examined the differences of cognitive workloads of short passage reading tasks across print and digital media (e.g., computer and tablet). In particular, we measured both objective and subjective variables of reading experience

of readers with eye-tracking data and survey analysis. Two laboratory experiments were conducted with undergraduate and graduate students in South Korea ($n = 32$; $n = 52$). For both experiments, students performed a number of short passage reading tasks across paper, computer, and tablet while wearing an eye-tracking device. After the experiment, students were asked to answer self-report questionnaires and to take reading comprehension tests. Results demonstrated two key findings. First, more cognitive workloads could be observed from both objective and subjective variables when reading digital media instead of print media. In particular, tablet readings demanded more cognitive workloads than print and computer readings, suggesting that it might be an inappropriate medium for short passage readings. Second, reading activities across print, computer, and tablet formats could be more psychological and subjective than we might think. Even though there were no differences in reading time and reading comprehension, readers felt they understood better and were more confident in their comprehension when reading from print than from digital media. Taken together, our results suggest that although reading on screen could exert higher levels of cognitive loads on readers, the negative effect could be insignificant for digital natives more than we might believe. Therefore, in current digital society, it is better for readers to choose reading media based on their preferences and purposes of their reading.

Keywords : Print Reading, Digital Reading, Reading Behaviors, Digital Generation,
Cognitive Workloads, Eye-movement Analysis

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Chapter 1. Introduction

In today's digital age, reading activity, especially the way people access reading media, has been transformed. As portable technology such as smartphones, tablets, and e-readers become prevalent, more people access digital media or utilize a mixture of paper and digital media for reading purposes. In Korea, from 2015 to 2017, reading time for both print and digital reading increased from 22.8 minutes to 23.4 minutes for adults and from 45 minutes to 49.4 minutes for students. Despite the decrease in average reading rate and volume on print media, the annual digital reading rate has increased from 10.2% to 14.1% for adults and from 27.1% to 29.8% for students (Ministry of Culture, Sports, and Tourism, 2017).

The concept of *reading* also has changed from decades ago, as the reading environment has undergone a dramatic transformation due to the spread of the Internet and mobile devices. Reading was once printed text on paper, but now it is emails, newspapers, online, and digital resources on a digital screen (Kurata, Ishita, Miyata, & Minami, 2017). With that in mind, previous studies of digital reading suggested that its characteristics differ from those of traditional reading. Digital reading involves nonlinear reading and skimming, making it distinctive from print reading, which is linear, fixed, and attentive (Hillesund, 2010). Moreover, Liu's (2005, p.700) study of reading behaviors towards digital reading suggested that people are spending "more time on browsing and scanning, keyword spotting, one-time reading, non-linear reading, and more reading selectively, while less time is spent on in-depth reading and concentrated reading. Decreasing sustained attention is also noted."

Extended studies on print or digital reading have shown a concern that digital reading could profoundly affect readers' abilities, preferences, and attitudes towards reading. Reading texts in printed form facilitates devoted reading (Kurata et al., 2017), whereas reading texts in digital form might increase cognitive loads of readers because of the features of hypertext online (DeStefano & LeFevre, 2007). With this concern in mind, several researchers have performed comparison studies of paper and digital readings with various age groups (Askwall, 1985; Cushman, 1986; Eshet-Alkalai & Geri, 2007; Mangen, 2008; Mangan & Kuiken, 2014; Mangen, Robinet, Olivier, & Valey, 2014; Lauterman & Ackerman, 2014; Hou, Rashid, & Lee, 2017). Although multiple studies have demonstrated phenomenological differences between print and digital readings, they have inconsistent findings. Nevertheless, differentiating between the reading effects of print and digital media results in a wide variety of outcomes.

To initiate a discussion of whether digital reading transforms the nature of traditional reading, it is first necessary to understand the differences between reading behaviors in print and digital readings in terms of cognitive and behavioral perspectives. Therefore, this study focused on observing cognitive workload differences based on objective and subjective behavioral measurements while having short passage readings on print, computer, and tablet. We had three important concepts for designing experiments.

First, we concentrated on short passage and linear text reading. Although past studies focused on readings of shorter lengths of texts consisting of one or few paragraphs (Rice, 1994), some researchers argued there has been a lack of empirical research examining differences of print and digital reading with narrative, linear, and longer lengths of texts (Graesser, Millis, & Zwaan, 1997; Mangen,

Walgermo & Brønnick, 2013). A recent study conducted experiments with longer lengths of texts containing an average of 1,000–2,000 words and found that students reading on printed medium resulted in higher comprehension scores than ones reading on computer screen (Wästlund, Reinikka, Norlander, & Archer, 2005; Mangen et al., 2013). Interestingly, we noticed that there has been a lack of eye-tracking research of comparison studies for short and linear passage readings; therefore, we observed short and linear passage readings with eye-tracking devices. Our study is one of few comparison articles observing readers' cognitive and behavioral differences while reading short passage and linear texts.

Second, we made comparison studies of short passage reading experiences across print, computer, and tablet media. Previous studies comparing print and digital readings utilize computers (Lauterman & Ackerman, 2014; Chen, Cheng, Chang, Zhen, & Huang, 2014) or e-readers (Zambarbieri & Carniglia, 2012; Margolin, Driscoll, Toland, & Kegler, 2013) as digital reading formats. We noticed that there have been limited studies utilizing both computer and tablet as the digital reading formats (Zambarbieri & Carniglia, 2012; Chen et al., 2014). With that in mind, we investigated reading experience differences across three different reading formats such as print, computer and tablet readings. Because tablets are becoming popular e-book reading devices due to their book-like characteristics, such as portability, usability, and interactivity (Chen et al., 2014), understanding how tablet reading differs from print and computer reading adds valuable insight to the previous literature.

Third, we chose college students who are known to be digital natives. They have a distinct set of natural characteristics regarding technology usage and adoption. Exposed to digital technology from early childhood, younger people are

developing learning abilities, such as multitasking and nonlinear processing, which are suitable to digital environments (Prensky, 2001). In particular, learning environments for digital natives, such as educational systems and course curricula, have adopted practices that facilitate learning and improve learning performance by creating, using and managing appropriate technological processes and resources (Robinson, Molenda, & Rezebek, 2008). Therefore, understanding cognitive and behavioral differences of reading activities across print and digital formats will provide an insightful knowledge that could be considered when designing curricula for reading activities regardless of the types of reading formats.

Chapter 2. Literature Review

2.1. Reading in the Digital Age

In the digital age, people access digital information through various types of digital media based on their purpose or preference. The digital environment seems to affect people's reading behaviors in a way not comparable to traditional reading behaviors. Even though digital media brought some advantages, such as interactivity and immediate access of information, which are absent in print reading, researchers showed concern that constant access to digital media changed people's reading behaviors in a negative way and threatened concentrated reading (Levy, 1997; Birkerts, 2006). For example, students who steadily watch television and spend less time on reading tend to have lower verbal scores on the SAT, which means they have trouble understanding longer sentences, embedded clauses, and advanced grammar structures (Healy, 2011).

Prior to understanding similarities or differences of print and digital readings, the definition of reading should be explicitly defined. As Singer and Alexander (2017, p.3) noted, we broadly conceptualized reading as "the dynamic process of understanding and drawing meaning from written text." This general concept of reading is also applied to reading activities occurred through both print and digital media. In particular, the key difference of print and digital reading is that "reading digitally requires [screen technology] that allows for a reading process that is similar to that of reading print" (Siegenthaler, Wurtz, Bergamin, & Groner, 2011, p.269).

Reading activities on screen has drastically increased among young people over the past years with the advancement of mobile devices and growing amount of digital information available. A survey report in 2012 found that people spent time on screen reading almost equal to the time on print reading (Stamford, 2012). This trend is also evidenced with China experiencing an increased rate of digital reading penetration from 24.5% in 2008 to 68.2% in 2016 (Statista, 2016). Korea has also experienced an increased rate of digital reading; for example, the annual digital reading rate has been increased from 10.2% to 14.1% for adults and from 27.1% to 29.8% for students over the course of time (Ministry of Culture, Sports, and Tourism, 2017). Interestingly, with the advancement of mobile devices such as tablet or iPad, people today seem to prefer multipurpose mobile devices for digital reading. The number of people using an e-book reader, which is a mobile device mainly for the purpose of reading, has declined. It could be evidenced from multiple statistical reports in which a share of Americans who utilize tablets or smartphones rather than e-book readers has substantially increased since 2011, and young adults heavily rely on smartphones and tablets as the most common device used to read online documents or e-books (Perrin, 2016). Moreover, a Nielsen (2015) survey also reported that e-book consumption via smartphone doubled from 7.6% in 2014 to 14.3% in 2015.

People's reading habits and attitudes towards print and digital reading have changed as they become more comfortable with and have easier access to digital readings. In particular, younger people are more familiar with information and entertainment in a digital format (Shahrize & Hasan, 2007), and they experience the shift of print reading to digital reading based on their preference and motivation (Liu, 2005; Shen, 2006; Kurata et al., 2017; Tanjung, Ridwan, & Gultom, 2017).

They have gradually developed screen-based reading behaviors and have their own reading strategies to cope with the digital environment (Liu, 2005). For example, Shen (2006) revealed that college EFL students preferred Internet-based reading over paper-based reading, and their reading habits changed to Internet-based reading from paper-based reading. Regarding online reading, students reported that they frequently access the Internet to read online information and often choose reading materials based on their reading purposes (Tanjung et al., 2017).

However, researchers have shown a concern that the rate of reading activity across all mediums and ages has declined over the years (Krashen, 2005; National Center for Education Statistics, 2013; Millot, 2015; Niemann, 2016). Adolescent reading rates have declined in recent years; the reading rate of adolescents has declined from 76% to 71% among 9-years-old, from 70% to 53% among 13-years-old, and from 64% to 40% among 17-years-old (National Center for Education Statistics, 2013). Moreover, according to research addressing the reading habits of American adults, the proportion of adults who read for pleasure has dropped from 79% in 2011 to 72% in 2015; the decline in reading is found across all media sources, e.g., print, digital, and audio (Millot, 2015). Such a decline in reading could be explained by the increased rates of digital activities (Niemann, 2016). Easy accessibility and portability of digital devices have provided people with more choices of activities, which influence reading for pleasure. Young adolescents spend most of their time engaged in digital activities, excluding spending time for work-related activities, for an average of 5.55 hours a day, 4.35 hours of which is screen time (Common Sense Media, 2015).

To sum up, the proliferation of digital or mobile devices has enabled people to consume various levels of information and has increased the digital reading

experience; however, the digital environment has begun to affect our notion of “what it means to read” and challenged our reading literacy, comprehension ability, and reading behaviors, such as habits and attitudes (Singer & Alexander, 2017). For example, studies further argue that the digital generation lacks the ability to read deeply and to sustain a prolonged reading engagement (Birkets, 2006). They are easily distracted from reading due to decrease in their attention span and loss of cognitive skills (Shillingsburg, 2012). In today’s digital age, it is inevitable that younger people are more likely to experience and develop screen-based reading behaviors. Therefore, understanding the differences in reading behaviors of the digital generation across print and digital media is worth investigating in future studies.

2.2. Research on Print vs. Digital Readings

Many researchers have investigated how print and digital reading differ in the context of cognitive and behavioral perspectives; such research spans many different fields of studies, such as psychology, education, and information technology (Askwall, 1985; Cushman, 1986; Eshet-Alkalai & Geri, 2007; Mangen, 2008; Mangen & Kuiken, 2014; Lauterman & Ackerman, 2014; Hou et al., 2017). The studies have found that print and screen reading differs significantly in the wide range of aspects. Some researchers revealed that people with digital reading take much longer to read and have lower comprehension scores compared with screen reading and might develop fragmented reading (Liu, 2005; Mangen et al., 2013). However, some studies have inconsistent findings with no significant

difference in reading comprehension and reading speed across print and digital readings (Singer & Alexander, 2017).

Such studies have limitations in which they mostly compared either paper and computer (Askwal, 1985; Cushman, 1986; Mangen et al., 2013; Lauterman & Ackerman, 2014) or paper and tablets or e-book readers (Siegenthaler et al., 2011; Hou et al., 2017). There is few research that makes comparisons across paper, computer, and tablet readings (Margolin et al., 2013; Jeong, 2012; Chen et al., 2014). Also, the interpretability of some previous findings is based on group comparisons across print and digital readings (Lauterman & Ackerman, 2014; Hou et al., 2017), which might have a lack of observing individual differences across reading media. Therefore, in our research, following the efforts of previous literature that examine the differences between print and digital reading media, we set our research goal to investigate individuals' differences on cognitive and behavioral aspects of reading behaviors across three widely used reading media: paper, computer, and tablet.

Differences in Reading Behavior Pattern. Studies have suggested that print and digital reading experience are related to different reading behaviors and techniques. Young people seem to develop digital brains with nonlinear reading and skimming, which compete with traditional ways of reading, the so-called close or linear reading. In digital reading, browsing and scanning has become a primary reading pattern (Liu, 2005). Such screen-based reading behaviors are often related to hyper-reading, which is defined as “reader-directed, screen-based, computer-assisted reading” (Sosnoski, 1999, p. 167). The hyper-reading often occurs when people read online or web information on screen, and the hypertext environment

provides readers with nonlinear reading behaviors that enable them to jump from site to site or from page to page (Liu, 2005; Boon & Higgins, 2003). There is considerable evidence that hyper-reading is significantly different from traditional reading because it stimulates different brain regions compared with linear reading (Shrestha & Lenz, 2007; Biedert, Dengel, Buscher, & Vartan, 2012). The nature of hypertext on digital reading may negatively impact people's sustained attention and related cognitive demands (Stoll, 1995; Levy, 1997; Liu, 2005; Birkerts, 2006). For example, Destefano and LeFevre (2007) suggested that hypertext environment tends to increase cognitive demands of decision-making and visual processing.

Even though digital reading lets readers have higher text engagements by enabling continuous reading (Turner & Hicks, 2015), readers seem to experience scanning and skimming more during reading. For example, people typically read information presented online in an F-shaped scanning pattern of reading the first two or three lines across the page and the scanned length gets shallower as the eyes move down to the screen (Jacob, 2006). Similar trends were observed in research on newspaper reading, which suggests that people scan more while reading the Internet version of a newspaper than when they read the traditional paper version (Holmqvist, Holsanova, Barthelson, & Lundqvist, 2003). Other studies also reported that unconscious skipping during the reading process occurred more frequently on digital media than on paper (Shrestha & Lenz, 2007; Biedert et al., 2012).

Research Question 1: How do objective variables of the reading experience differ when reading print or digital media (e.g., computer and tablet)? Can these measures be empirically categorized to measure cognitive workloads?

Eye movements, Readings, and Cognitive Workloads. To examine the cognitive differences of reading behavior across print and digital media, we employed eye-tracking technology. Eye movement data could offer valuable insight into whether such cognitive and skimming tendencies occur when reading from print or digital media. For the past few decades, eye movement data has been used in cognitive process studies in reading, such as newspapers and print advertisements (Wedel & Pieters, 2000; Rayner, Rotello, Stewart, Keir, & Duffy, 2001; Holsanova, Rahm, & Holmgvist, 2006; Jarodzka & Brand-Gruwel, 2017). Even though most eye-tracking-based research focused on understanding the process of reading a word or sentence (Hyönä, 1993; Hyönä & Niemi, 1990; Hyönä & Olson, 1995; Vauras, Hyönä, & Niemi, 1992), a relatively small number of eye-tracking-based experimental studies have been conducted to compare print and digital media reading (Kretzschmar, Pleimling, Hosemann, Füssel, Bornkessel-Schlesewsky, & Schlewsky, 2013). Therefore, we utilized eye movement technology in the comparison of reading behaviors across reading media.

Cognitive workload can be considered as the amount of mental efforts exerted by an individual in response to the demands of tasks, either cognitive or physical, that require the limited information processing capability of the human brain (Wickens, 2008; Wickens, Hollands, Banbury, & Parasuraman, 2013). Such cognitive workload can be accessed through physiological measurements (i.e., eye movements) meaning that such measurements would have noticeable changes as

task demands (Wierwille & Eggermeier, 1993; Stanton, Salmon, Walker, Baber, & Jenkins, 2005). Eye movement measures are one form of well-researched physiological eye-tracking technology that has enabled us to have more objective measurements for cognitive process and workloads in reading activities (Rayner, 1998, 2004). Researchers argued that cognitive processes while reading can be studied based on the relationship between the behavior of eye movement activities and cognition (Kahneman, Beatty, & Pollack, 1967) and the evolution eye measurements of reader's cognitive workload through eye movement types and pupillary responses (Buettner, 2013; Zagermann, Pfeil, & Reiterer, 2016). The commonly studied eye measurements are pupillometry, eye blinks, and eye fixations, including fixation frequency, fixation durations, saccadic duration, and gaze distribution (Holland & Tarlow, 1975; Kramer, 1990; Brookings, Wilson, & Swain, 1996).

The pupillometry, the variation in pupil diameter, has been interpreted as indicators of second-to-second variation in the amounts of workloads obtained by the task demands (Kahneman et al., 1967). The pupil sizes (left and right) are positively related to the difficulty of the cognitive task, and the magnitude of pupillary dilation appears to be a function of processing mental efforts required for the tasks (Iqbal, Zheng, & Bailey, 2004; Beatty & Kahneman, 1966; Beatty, 1982; Marquart, Cabrall, & de Winter, 2015). Even though pupillary changes are thought to be linked with cognitive processing, researchers should be aware that pupillary changes can be influenced by other factors than cognitive workloads, such as the amount of light (Karamer, 1990).

Moreover, eye fixations, including fixation duration and fixation frequency, are other measurements for cognitive workloads (Coral, 2011). Fixations are the static

gaze movement occurring when readers continuously move over the text while fixation duration is the time duration when the eyes remain relatively still (Just & Carpenter, 1976, 1980). Fixation duration is an established indicator of the difficulty of perceptual and/or cognitive processing in the reading (Stanton et al., 2005; Just & Carpenter, 1980). However, eye movements, such as fixation duration and number of fixations, could be influenced by text difficulty, text characteristics, and screen contrast (Rayner, 1998; Rayner, Pollatsek, Ashby, & Clifton, 2012).

Reading Time and Reading Comprehension. We investigated reading time and reading comprehension as objective variables of the reading experience. First, reading time should be taken into consideration to better understand possible

Table 1. Summary of Eye-related Measurements and Their Relationship to Increased Cognitive Workload (Coral, 2011)

Indicator of Increased Cognitive Workload	
↑	Blink Duration
↑	Blink Interval
↑	Blink Frequency
↑	Saccade Rate
↑	Saccade Peak Velocity
↑	Saccade Peak Velocity
↑	Saccade Amplitude
↑	Pupillometry
↑	Pupil Dilation
↑	Fixation Frequency
↑	Fixation Durations
↑	Horizontal Fixations
↑	Vertical Fixations
↑	Mean Dwell Time
↓	Saccade Extent
↓	Blink Rate
↓	Area of Visual Field

discrepancies in reading comprehension (Kerr & Symons, 2006). Previous research showed that people read slower on a screen than on paper (Gould & Grischkowsky, 1984; Mills & Weldon, 1987; Moore & Zabrocky, 1995). However, some studies reported that reading time does not vary significantly across print and digital media (Askwall, 1985; Cushman, 1986; Zambarbieri & Carniglia, 2012). A study examining the differences of a child's reading speed and reading comprehension between print and digital readings found that children read slower on computers than on printed media. However, children showed no significant difference in reading time when given sufficient time for learning (Kerr & Symons, 2006).

Moreover, numerous research studies examine reading comprehension differences between print and digital media. Some studies found that people who prefer print reading media are less overconfident and comprehend better than people who prefer digital reading media (Lauterman & Ackerman, 2014). Research on high school and college student abilities to critically read newspapers suggested that printed newspaper readers are more likely to have critical reading and better comprehension skills than digital media readers (Tewksbury & Althaus, 2000; Eshet-Alkalai & Geri, 2007). Another research study indicated that reading from electronic screens disturbs the formation of cognitive maps of the structure of text, which may be reflected in poorer comprehension and ultimately poorer recall of the presented material (Kerr & Symons, 2006). However, a recent study found that the materiality of the medium does not influence reading comprehension, but text presentation facilitates or impedes a reader's ability to form cognitive maps that influence the reading process (Hou et al., 2017). Moreover, reading comprehension is an indirect measure of cognitive load of the reading material. A study suggested that reading comprehension is an objective and indirect measure of cognitive

workload because it is considered a knowledge acquisition score that “depends on processes of information storage and retrieval that may be affected by cognitive load” (Bruken et al., 2003, p. 56).

Research Question 2: How do subjective variables of the reading experience differ when reading print or digital media (e.g., computer and tablet)? Can these measures be empirically categorized to measure cognitive workloads?

Subjective Impressions of Reading Experience. Subjective impressions of the reading experience may influence overall reading activity of readers (i.e., reading time and reading comprehension). According to a study comparing and examining the relationship between subjective and objective variables across reading experiences of paper and tablet media, subjective assessment of reading pleasantness and readability differed with reading efforts measured by EEG and eye-tracking devices (Kretzschmar et al., 2013). With that in mind, this study also explored various subjective variables of reading experience, such as perceived difficulty, understanding, confidence, fatigue, and immersion, across different reading media.

Subjective assessments of difficulty, understanding, and confidence variables of reading media may appear as different levels of reading comprehension. Studies find that measuring one’s perceived difficulty or understating of the reading material is a direct and subjective measure of cognitive workloads (Kalyuga, Chandler, & Sweller, 1999, 2000). Interestingly, according to a study of screen inferiority, screen readers showed a higher level of confidence in their reading comprehension when their actual reading comprehension was worse than perceived

(Lauterman & Ackerman, 2014). People's confidence in their performance could be an influencing variable that leads them to think they achieved an adequate level of knowledge when, in fact, their reading comprehension lowered (Nelson & Narens, 1990; Ackerman & Goldsmith, 2011).

Eye fatigue is defined as the level of eye fatigue while performing particular activities, and it could be one of the variables that distinctively differentiates print and digital reading media. People felt greater visual fatigue and tiredness after reading on a screen (i.e., computer and e-books) than after reading printed books because of the characteristics of a screen, such as display contrast and resolutions (Cushman, 1986; Macedo-Rouet et al., 2003; Kang et al., 2009; Jeong, 2012). Understanding the influence of digital screen time on eyes helps to investigate cognitive loads while performing reading activities. According to a cognitive map mechanism, eye fatigue imposes an extra load on cognitive processing systems because digital environments distract a person from forming a mental map of text during reading (DeStefano & LeFevre, 2007; Hou et al., 2017). According to a study comparing cognitive maps and reading media materiality mechanisms of paper and screen reading, people experience more eye fatigue when exposed to reading from a screen than from paper; such eye fatigue influences a reader's abilities to form cognitive maps (Hou et al., 2017).

Moreover, immersion is defined as the level of engagement while performing particular activities. This is an important variable that measures the enjoyment of reading activity (Witmer & Singer, 1998; Hou, Nam, Peng, & Lee, 2012; Hou et al., 2017). Several studies compared the level of immersion between print and digital reading (Magen & Kuiken, 2014; Mengen, Robinet, Olivier, & Valay, 2014; Hou et al., 2017); however, studies that measure immersion are limited. Such studies

reported that screen readers demonstrated lower levels of perceived immersion and engagement than print media readers did. One of the possible explanations could be the intangibility of the screen text, which could lead people to read in a shallower way and disturb the formation of cognitive maps (Mangen, 2008; Hou et al., 2017).

Comparison of Objective and Subjective Variables. In this study, subjective variables of reading experience were compared with the objective variables of reading experience such as reading time and reading comprehension. Because reading is a multifaceted process with word recognition, reading strategies, prior knowledge, comprehension, vocabularies, fluency, and motivation to read (Sanford, 2015), examining both objective and subjective variables can help in viewing the problems with multidimensional perspectives. From a cognitive science perspective, a person's perception of her own behavior (e.g., perceived level of understanding or difficulty) does not always reflect the neural activities or the objective measures of behavior (e.g., reading comprehension) (Rayner, White, & Liversedge, 2006). For example, a research study investigating reading differences across media measured with EEG and eye-tracking software revealed that young adults showed comparable fixation duration and theta activity while reading from all three media; however, the level of reading comprehension did not differ across media (Kretzschmar et al., 2013). Therefore, in this study, we look for objective and subjective variable differences between print, computer, and tablet readings.

Chapter 3. Study 1

3.1. Research Question and Hypothesis

Research Question 1: How do objective variables of the reading experience differ when reading print or digital media (e.g., computer and tablet)? Can these measures be empirically categorized to measure cognitive workloads?

The purpose of study 1 was to investigate differences in objective variables of reading experience across print and digital media (e.g., computer and tablet). In this study, we utilized three different eye movement measures—pupillometry (left, right), fixation duration, and fixation frequency—and two reading ability measures—reading time and reading comprehension. We designed the following hypotheses:

Hypothesis 1: The levels of *objective variables* of reading experience will be different across print and digital readings (e.g., computer and tablet readings).

H 1-1: *Eye movement measures* will be different across print, computer, and tablet reading.

H 1-2: *Reading time* will be different across print, computer, and tablet reading.

H 1-3: *Reading comprehension* will be different across print, computer, and tablet reading.

3.2. Methods

3.2.1. Experimental Design

This experiment employed a within-subject comparison experiment design. A participant performed short passage readings from three different media formats: paper, computer, and tablet. The basic activities in the experiment involved performing six different reading tasks across print, computer, and tablet reading media with wearing an eye-tracking device. To prevent possible carryover effects, each participant received a random order of reading media, and each reading material was also randomly distributed across assigned reading tasks. Therefore, all participants received a different order of reading media and reading materials across media. After each reading, participants were asked to answer reading comprehension questionnaires regarding what they read.

For the entire experiment process, participants wore Tobii Pro Glasses 2, which captured real-time observations of the user's gaze data. Tobii Studio 1.3 and Tobii Pro Lab 1.73 software were employed to extract and analyze eye-tracking data. All text was presented via three media formats. Each reading material was designed to have same page layouts with A4-size paper, 10-pt font size, Nanum Myeongjo typeface, and 8-pt line spacing. Participants completed print reading using A4-size paper, which designated the amount of text printed. They also completed the digital portions of the reading using a 21.5" iMac with Retina display monitor at a resolution of 1920 x 1080 pixels and a 12.3" Surface Pro with PixelSenseTM display features at 267 PPI resolution. The digital texts were saved as PDF files and read using Adobe Reader for Windows. To minimize any possible distractions,

the size of print and digital texts was controlled by a dimension of approximately 8.3 x 11.7-inch surface area, or a diagonal length of between 12.3 and 13.9 inches.

3.2.2. Recruitment

Participants of this experiment were recruited from various universities located in Seoul and Gyeonggi province area of South Korea. Participants who showed a willingness to participate in this study contacted one of researchers to set-up a date of participation. Before the actual experiment, all participants were fully informed about the aim and method of the experiment and completed a written informed consent.

3.2.3. Procedures

Participants were invited to a quiet room setting as they arrived at the location at the scheduled time. As each participant arrived, an instructor greeted and explained the objective and overall process of the study; participants were informed that they would perform six different reading tasks, which were randomly assigned, while using an eye-tracking device. Then, the participants read the instructions and signed an informed consent form approved by Institutional Review Board (IRB). Before the experimental session, participants were asked to take a pre-survey questionnaire and a reading comprehension (RC) test.

The experiment was divided into six different readings and participants had a one-minute break between the readings. Before the reading session begins, participants were instructed to read the provided text across various media as they normally would. While participants performed each reading task, the reading time that they took to finish each text passage was recorded. However, to reduce any

influence of time-pressure, participants were not informed that they were being timed.

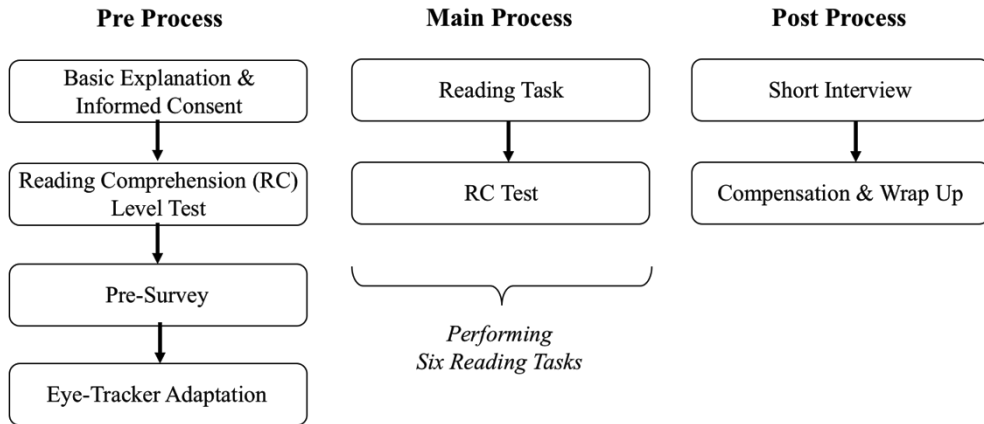


Figure 1. Experiment Process of Study 1

Participants were asked to wear the eye-tracking device and were randomly assigned six reading tasks of reading independent texts across three different media. For each medium, participants read two independent reading texts. After each reading task, participants were asked to answer questions assessing reading comprehension of what they read. After finishing all reading tasks, participants were debriefed and received a \$10 compensation for their time.

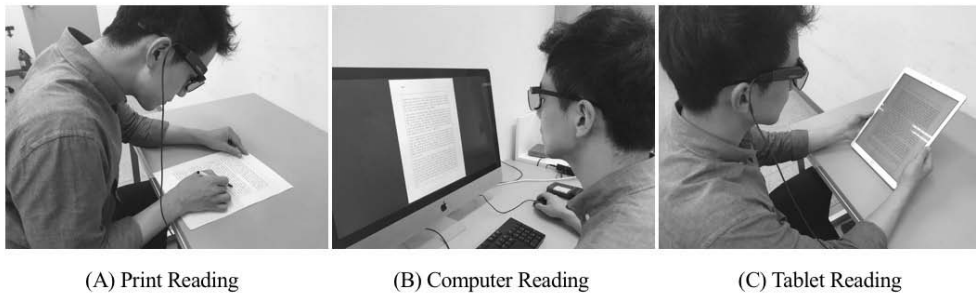


Figure 2. Examples of Experiment Conditions with an Eye-tracking Device

3.2.4. Participants

A total of 32 undergraduate and graduate students, who are digital natives familiar with the use of Internet and digital media devices, participated in this experiment (Prensky, 2001). We assumed that this generation is a suitable sample for this research because they are familiar with both paper and digital devices and can be opinionated about reading activities on both print and digital devices. All participants had prior experience with reading comprehension-based tasks and were very familiar with a variety of reading media (paper, computer, and reasonably familiar with reading in tablet devices).

3.2.5. Reading Materials

Each participant read six texts in total for this experiment. A set of two texts for each medium (paper, computer, and tablet) was assigned to participants. The six reading materials chosen for the experiment had an A4-size length of texts composed of four paragraphs. The materials were chosen from a reading comprehension session from the Korean Broadcasting System's (KBS) Korean Language Proficiency Test, which is a nationally authorized official language test examining Korean linguistic understanding and ability for both native and nonnative speakers. Previous literature has utilized the texts and questionnaires because linguistic experts designed from the linguistic and other professional fields (Kim et al, 2015). Therefore, we believe that the reading materials could be reliable and used for our experiment.

Only expository reading materials were selected for this experiment for the following reasons. First, expository texts contain the following structural elements: main idea, major ideas, and supporting details. Some researchers argue that understanding text structure is an important factor for reading comprehension (Meyer & Poon, 2001; Snyder, 2010). Second, our targeted subject population for the experiment included students who are normally exposed to academic and professional-related readings; therefore, we selected expository texts to provide a natural environmental settings.

To adjust the levels of text language and comprehension questions, we selectively chose the materials based on the following guidelines. First, all text should be of similar length and readability. The length of the text was between 284 and 307 words and composed of four paragraphs (each paragraph contained approximately 51–107 words). Second, the level of texts and questionnaires should be similar; we chose easy to intermediate comprehension level texts and questionnaires, which had more than a 60% correct answer rate from past test results. Third, the text should cover current affairs and educational contents delivering factual information about various fields of studies. Current affairs and educational contents are suitable to test each participant's reading comprehension ability, especially their understanding of the overall context and ability to infer factual information. Fourth, each text should present various topics. Because participants could have expertise in their study areas, different topics should be randomly presented across reading media to minimize possible influence by their background knowledge. Thus, six reading texts covered six different topics including philosophy, economics, politics, engineering, biology, and history.

3.2.6. Measures

Participants first completed a pre-survey with 14 questions measuring 9 variables: demographics, usage patterns of digital devices, medium preference, familiarity and utility, reading habits, reading ability, skepticisms on digital reading, and self-perception. To directly and indirectly measure cognitive workloads, we used three eye movements—*pupillometry*, *fixation duration*, and *fixation frequency*—and two reading ability variables—*reading time* and *reading comprehension*.

Pupillometry. We utilized mean pupil diameter change (MPDC) for both eyes (left, right). To get the variance of pupil diameter, we subtracted the minimum average pupil size (mm) from the maximum average of pupil size (mm) of participants while performing each reading task. Then, the average of MPDC for each reading task was calculated to compare the results across reading media.

Fixation duration. We analyzed fixation duration by calculating the average fixation duration for area of interest (AOI) and examined the average information processing time for texts presented for the reading (in seconds).

Fixation Frequency. To have the number of fixations, the eye movement type for each gaze was counted for the analysis. When filtering out loading fixations, cut-off ranges were defined as 100 ms for low cut-off and 500 ms for high cut-off. These cut-off ranges correspond to a standard deviation (SD) of 2 above and below the average.

Reading Time. The length of time for each reading activity was measured and recorded from when the participant's eyes started to move for reading until his/her eye activities ended (in seconds). All reading activities were recorded via the eye-

tracking device. The reading time was recorded and analyzed from the eye-tracking software. The results of the data were double-checked by researchers.

Reading Comprehension. For each reading task, participants were asked five comprehension questions based on the reading materials they had. The questions were composed of true/false test items that assessed a participant's general understanding of the reading material and ability to identify whether statements of fact are correct. Scoring rules were determined *a priori* for the reading comprehension measure. Each correct item was scored as 1 point, and the maximum possible score on comprehension for each task was 5 points. The scoring method resulted in a maximum score of 10 points for each medium.

3.2.7. Data Analysis

To test hypotheses 1, Statistical Package for the Social Sciences (SPSS) Version 23 was used to examine the statistical difference of objective variables across the three different media. For the statistical analysis of data, the following three steps were performed.

First, a normality test was conducted on each variable. Because we have a small sample size ($N < 50$), we used the Shapiro–Wilk Test. The results showed that all variables—*pupillometry (left, right)*, *fixation durations*, *fixation frequency*, *reading time*, *reading comprehension*—do not follow a normal distribution ($p < 0.05$). Even though the data does not follow a normal distribution, the data can be considered a normal distribution because skewness and kurtosis are between -1 and 1 (George & Mallery, 2010; Gravetter & Wallnau, 2014).

Second, in consideration of the sample size and the result of normality, repeated measurements with ANOVA (rmANOVA) with the significance threshold

of $p < 0.05$ were accomplished to determine how three dependent variables—print, computer, and tablet readings—differ for the measured independence variables. All analyses were corrected using Bonferroni *post-hoc* tests.

3.3. Results

3.3.1. Participants and Their Perceptions of Reading Media

A total number of 32 undergraduate and graduate students participated in this experiment; however, only 29 samples were used for eye movement and statistical analyses ($n = 19$ female, $n = 10$ male) due to the problem with the eye-tracking data. Participant birth years ranged from 1989 to 1998, with a mean age of 27 (or those born in 1992.28) and a SD of 3.99 years. The sample represented a wide variety of majors: 36.7% engineering, 16.7% applied science, 3.3% humanities, and 20% social sciences. RC test scores showed that all participants had a similar level of reading comprehension ability ($M = 8.93$, $SD = 1.07$). Participants finished the RC test with the reasonable time range of 10–25 minutes ($M = 14.5$, $SD = 2.96$).

Interestingly, students reported that they selectively use certain reading media depending on their reading purposes. Only 20% ($n = 6$) reported that they do not differently utilize media for reading. For daily reading medium, 56.7% of participants ($n = 17$) answered that they utilize computers or desktops, while 27.6% of participants ($n = 8$) utilize paper. 13.3% of participants ($n = 4$) reported that they equally utilize all three mediums—paper, computers or laptops, and tablets—for their daily reading. However, about half reported that they prefer and are familiar with print reading than digital reading via computers or laptops and tablets. When reading digitally, the main digital contents are news articles (46.7%), information searching and reading (20%), social media (16.7%), and learning materials (6.7%). Moreover, participants did not have skepticism over digital reading, which means they did not have a bias towards digital reading, have positive feelings over digital

reading, and have a belief that digital reading enables their reading experience more effective ($M = 3.51$, $SD = 0.64$).

3.3.2. Objective Variables of Reading Experience

According to our result, the eye movement variables, namely *pupillometry*, *fixation duration*, and *fixation frequency*, were statistically different across print, computer, and tablet readings ($p \leq 0.05$). Because the eye-movement variables were utilized to indirectly measure cognitive workloads of three different readings, the results partially suggested there would be more cognitive workloads when reading on digital devices than printed formats. However, the differences were only observed

Table 2. The Result of Repeated ANOVA for Objective Variables across Print, Computer, and Tablet Readings

	Print Reading (PR)	Computer Reading (CR)	Tablet Reading (TR)	$F(df)$	Sig.	η^2
	Mean \pm SD	Mean \pm SD	Mean \pm SD			
Pupillometry (left)	2.77 \pm 0.20	3.20 \pm 0.22	3.23 \pm 0.22	10.48 (2)	0.001 **	0.49
Pupillometry (right)	2.97 \pm 0.20	3.39 \pm 0.18	3.53 \pm 0.21	8.37 (2)	0.002 **	0.43
Fixation Duration	234.93 \pm 11.82	283.12 \pm 21.36	275.38 \pm 17.30	3.70 (1.30)	0.054 *	0.13
Fixation Frequency	4929.86 \pm 416.12	4760.82 \pm 470.50	4344.78 \pm 359.60	2.46 (1.80)	0.055 *	0.21
Reading Time	136.29 \pm 9.63	128.73 \pm 11.15	125.18 \pm 8.66	0.975 (2)	0.393	0.08
Reading Comprehension	8.59 \pm 0.22	8.52 \pm 0.20	8.59 \pm 0.28	0.04 (2)	0.965	0.03

^a Statistical significant differences are indicated as *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

^b Data presented with *pupillometry* in mm; *fixation duration* in second; *fixation frequency* in counts, *reading time* in sections; *research comprehension* with scores out of 1

^c All statistical numbers were rounded up to two-decimal places, with the exception of p -values

either between print and computer readings or between print and tablet readings. There were no statistical significant differences observed between computer and tablet readings.

In particular, *pupillometry* had statistically significant differences across print, computer and tablet readings. The trend of pupillometry was that the variance of pupil diameters was larger for computer and tablet readings compared with print reading ($p \leq 0.01$). Moreover, *fixation duration* and *fixation frequency* were close to being statistically significant across print, computer, and tablet readings ($p \geq 0.05$). Longer fixation duration was observed between print and computer readings with a statistical significance ($p = 0.046$) and between print and tablet readings with a statistical significance ($p = 0.028$). Moreover, for fixation frequency, the difference was only found between print and tablet readings, meaning that print reading has more fixations than tablet readings ($\text{diff} = 585.08$, $p = 0.040$). With the result of pupillometry and fixation duration, we could assume that less cognitive workloads occur when reading from paper than from either computer or tablet.

Moreover, *reading time* and *reading comprehension* could be used as indirect measures of cognitive workloads for reading activities. In hypotheses 1-2 and 1-3, we assumed that both reading time and reading comprehension would be different across print, computer, and tablet readings. Unlikely to our assumption, the results showed that reading time and reading comprehension were not statistically significant between print, computer, and tablet readings. For both reading time and reading comprehension, Mauchly's test indicated that the assumption of sphericity had been accepted ($\chi^2(2) = 4.64$ and $p = 0.098$; $\chi^2(2) = 0.96$ and $p = 0.618$). The result showed there is no statistically significant effect of reading time and reading comprehension across three different reading media. (Wilk's Lambda = 0.92, $F(2,$

22) = 0.98, and $p = 0.393$; Wilk's Lambda = 0.99, $F(2, 25) = 0.04$, and $p = 0.965$).

Therefore, hypotheses 1-2 and 1-3 were not validated.

Table 3. Post-hoc Comparison of Objective Measurements
between Print Reading (P), Computer Reading (C), and Tablet Reading (T)

	PR - CR		PR - TR		CR - TR	
	diff	Sig. ($p < 0.05$)	diff	Sig. ($p < 0.05$)	diff	Sig. ($p < 0.05$)
Pupillometry (left)	-0.45**	0.002	-0.47**	0.000	-0.03	0.774
Pupillometry (right)	-0.42**	0.008	-0.56**	0.001	-0.14	0.406
Fixation Duration	-39.20*	0.046	-31.45*	0.028	7.74	0.673
Fixation Frequency	169.04	0.590	585.1*	0.040	416.04	0.080
Reading Time	7.56	1.000	11.11	0.515	3.54	1.000
Reading Comprehension	0.15	0.798	0.00	1.000	-0.15	0.826

^a diff = mean of condition 1 – mean of condition 2

Statistical significant differences is indicated as *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

^b PR=Print Reading, CR=Computer Reading, TR=Tablet Reading

^c Data presented with *pupillometry* in mm; *fixation duration* in second; *fixation frequency* in counts, *reading time* in sections; *research comprehension* with scores out of 1

^d All statistical numbers were rounded up to two-decimal places, with the exception of p -values

Chapter 4. Study 2

4.1. Research Question and Hypothesis

In study 1, we observed the differences of objective variables across print, computer, and tablet readings with the measurements of pupillometry, fixation duration, fixation frequency, reading time, and reading comprehension. The results of study 1 indicated the three eye movement measurements were significantly different across paper, computer, and tablet readings; however, reading time and reading comprehension were not significantly different.

Interesting phenomena were observed from interview reports in which participants perceived that they read more thoroughly on print reading compared with digital readings and showed more confidence in reading comprehension on print reading than digital readings. Most reported that they experienced materialistic discomforts, such as screen distractions, when reading from digital media. The following comments are the examples of our interview data.

One respondent (P007) answered, “I think the reading comprehension results would be better on print reading. There were less eye-fatigue while reading on paper, so I could more concentrate on and had a better understanding.” Another respondent (P014) reported, “I felt that print readings were more immersive and I performed and understood better at readings on paper. Especially, I was uncomfortable reading from tablets because I am not familiar with the device.” As Rayner et al. (2006) suggested, subjective impressions of readers might not reflect the objective measures of reading activity, such as reading speed and reading comprehension. This allowed us to question how the readers would feel about or

judge their reading experience across print and digital media, and how the subjective judgment differs from the actual reading comprehension.

Therefore, extending to study 1, we added subjective variables of reading experience, namely the levels of perceived difficulty, perceived understanding, perceived confidence, perceived fatigue, and perceived immersion. Our goal for study 2 is to observe how objective and subjective variables of reading experience would differ when reading print and digital media. The following research question and hypotheses were designed for this study:

Research Question 2: How do subjective variables of the reading experience differ when reading print or digital media (e.g., computer and tablet)? Can these measures be empirically categorized to measure cognitive workloads?

To validate the result of study 1, objective variables of reading experience were also presented in this study (refer to 3.1.).

Hypothesis 1: The levels of *objective variables* of reading experience will be different across print and digital readings (e.g., computer and tablet readings).

H 1-1: *Eye movement measures* will be different across print, computer, and tablet reading.

H 1-2: *Reading time* will be different across print, computer, and tablet reading.

H 1-3: *Reading comprehension* will be different across print, computer, and tablet reading.

Hypothesis 2 was added to measure the levels of subjective impressions of reading experience across print, computer and tablet readings. The measures were designed

to examine how participants thought or felt about the reading texts that they read from different types of media.

Hypothesis 2: The levels of *subjective variables* of reading experience will be different across print and digital readings (e.g., computer and tablet readings).

H 2-1: *Perceived difficulty* will be different across print, computer, and tablet readings.

H 2-2: *Perceived understanding* will be different across print, computer, and tablet readings.

H 2-3: *Perceived confidence* will be different across print, computer, and tablet readings.

H 2-4: *Perceived fatigue* will be different across print, computer, and tablet readings.

H 2-4: *Perceived immersion* will be different across print, computer, and tablet readings.

4.2. Methods

While we used the same experimental design and materials as in study 1, the following changes were addressed for study 2:

- ✓ *Experiment process*: The experiment was divided into two sessions to observe subjective impressions of reading experience in the context of natural reading and unnatural reading environment. For session 1, participants performed reading tasks without reading an RC comprehension test.
- ✓ *Reading materials*: Three reading materials for session 1 were added from KBS's Language Proficiency Test under the guidelines designed when selecting reading materials for study 1 (refer to Section 3.2.5).
- ✓ *Survey Questionnaires*: Self-report questionnaires regarding subjective impressions of presented reading materials were newly designed. During sessions 1 and 2, participants answered the questionnaires prior to the reading comprehension test for each reading task.
- ✓ *Tablet type*: A 12.9-inch iPad Pro with retina display and resolution of 2732 x 2048 pixels was utilized for this experiment. In study 1, we utilized the Microsoft Surface Pro with PixelSense™. Because Surface Pro with PixelSense™ is not a commonly used portable device compared with other types of tablets, we decided to change the medium to an iPad that is more commonly used. According to IDC Worldwide Quarterly, PCD Tracker reported that Apple has dominated the tablet market, with a market share of 26.8% in 2017 and 24.3% in 2016 (Russel, 2018).

4.2.1 Participants

A total of 52 undergraduate and graduate students ($n = 32$ females, $n = 20$ males) participated for study 2. Participants were born between 1989 and 1998 ($M = 1993$, $SD = 2.18$). The samples represented a wide variety of majors: 29.8% humanities, 14.9% social sciences, 25.5% applied sciences, and 29.8% engineering. All participants had a similar level of reading comprehension ability ($M = 8.79$, $SD = 0.88$). They finished an entire test set within 8.37–26.43 minutes ($M = 14.20$, $SD = 3.80$). Moreover, during the experiment, participants finished each reading task within 3.84 minutes, with a mean of 1.94 minutes ($SD = 0.61$) for print reading, a mean of 1.78 minutes ($SD = 0.60$) for computer reading and a mean of 1.83 minutes ($SD = 0.55$) for tablet reading. Moreover, they all had prior experience with print and digital readings, and they are familiar with a variety of reading media. They were very familiar with reading from paper and computer but reasonably familiar with reading from tablet device.

4.2.2 Procedures

Similar to the procedures for study 1, the participants were invited to a quiet room setting as they arrived at the location at the scheduled time. The instructor gave a brief introduction of the study and explained the purpose and experiment process. Then, the participants were asked to read the instructions and sign for the informed consent form approved by Institutional Review Board (IRB). Prior to experiment sessions, participants completed a pre-survey questionnaire and an RC test.

The experiment was divided into two sessions, and the participants had a five-minute break between sessions. For each session, participants were informed about the process and instructed to read the provided text across various media as they

normally would. While participants performed each reading task, the reading time for completing each reading task was recorded. Participants were not informed that they were being timed to reduce any influence of time-pressure for finishing reading activities.

Session 1. After wearing an eye-tracking device (see Figure 2), the participants were asked to read three randomly assigned independent text across three different media. After each reading, participants were asked to answer self-report questionnaires assessing subjective impressions of reading experience. Participants had a one-minute break between each reading task.

Session 2. After a five-minutes break, participants performed session 2, which participants completed a RC test for each reading task. While wearing an eye-tracking device, they were asked to read six randomly assigned reading tasks across three different media. After completing each reading task, participants were asked to complete a self-report questionnaire and to take an RC test. Participants read two independent reading texts for each reading medium and had a one-minute break between each reading task.

Interview. After finishing the entire session, participants had a five-minute interview with an instructor. The participants were informed that their interviews would be recorded. For the qualitative analysis, they were asked questions about their reading experiences across three different media. Then, the participants were debriefed and given a \$10 compensation for their time.

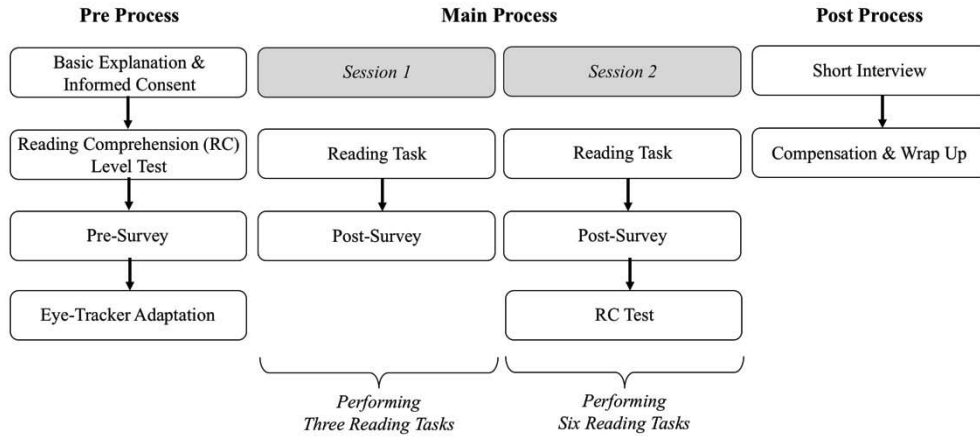


Figure 3. Experiment Process of Study 2

4.2.3 Measures

With the five objective variables measured in the study 1—*pupillometry*, *fixation durations*, *fixation frequency*, *reading time*, and *reading comprehension*—five subjective measures—*perceived understanding*, *difficulty*, *confidence*, *fatigue*, and *immersion*—were also measured in study 2.

Perceived understanding. The levels of understanding were measured by asking, “How strong did you understand about the reading you had?” The scale ranged from 1 (poorly understood) to 4 (definitely understood) and was used to measure how participants felt about their understanding of the assigned reading material. A higher score indicates that participants felt they understood better about what they read.

Perceived difficulty. The levels of perceived difficulty measures how difficult the participants felt about the assigned reading task. It was assessed by asking, “How difficult did you feel about the reading you had?” A perceived difficulty score was calculated for each reading task, ranging from 1 (very easy) to 4 (very

difficult). The higher score indicates that participants felt the assigned reading was more difficult.

Perceived confidence. The levels of perceived confidence measures how confident participants felt about their comprehension of assigned reading tasks. It was measured by asking, “How confident are you about your reading comprehension?” The scale ranged from 1 (very unconfident) to 4 (very confident). A higher score indicates that participants felt they are more confident about their comprehension.

Perceived fatigue. The levels of perceived fatigue was measured from the two following questions taken from previous literature (Hou et al., 2017): “When I read the text, I experienced eye fatigue (reverse-scored)” and “When I read the text, I felt comfortable.” The Likert scale, ranging from 1 (very unlikely) to 4 (very likely) was used to measure the visual fatigue of their reading experience. A higher score indicates that participants felt less fatigue when reading the text.

Perceived immersion. The levels of perceived immersion were measured from the two following questions from previous literature (Hou et al., 2017): “When I read the text, I got really immersed in it” and “When I read the text, I just could not focus on the text (reverse-scored).” The Likert scale ranged from 1 (strongly disagree) to 4 (strongly agree) and was used to measure whether participants had a focused reading. A higher score indicates that participants experienced more immersion while reading the assigned text.

4.2.4 Data Analysis

SPSS Version 23 was used to examine the statistical difference of objective and subjective variables of reading experience across paper, computer, and tablet. The following three steps were performed.

First, a normality test was conducted on each variable. Because we have a small sample size ($N < 50$), we used the Shapiro–Wilk Test. The results showed that all variables do not follow a normal distribution with $p < 0.05$. Although the data does not follow a normal distribution, the data were considered a normal distribution because skewness and kurtosis are between -1 and 1 (George & Mallery, 2010; Gravetter & Wallnau, 2014). Second, in consideration of the sample size and the result of normality, rmANOVA was performed to determine how three dependent variables—paper, computer, and tablet readings—differ for the measured objective and subjective independent variables. Third, a Bonferroni *post-hoc* test was utilized to observe statistical differences between the two types of reading media (e.g., paper and computer, paper and tablet, computer and tablet).

4.3. Results

4.3.1. Participants and Their Perceptions on Reading Media

In this study, a total of 52 undergraduate and graduate students who showed an interest in participating were recruited. However, only 47 participants ($n = 32$ females, $n = 15$ males) were selected during the process of data cleaning; 5 participants were excluded from data analysis due to problems with the eye-tracking-based data collection.

All participants had prior experience with comprehensive reading with print, computer, and tablet readings. However, a reasonable number of participants were familiar with reading from tablet devices: 51.1% of participants ($n = 24$) use paper as their main medium for daily reading, while 29.8% of participants ($n = 14$) use computers and 19.1% of participants ($n = 9$) use tablets as their daily reading devices. Interestingly, 83% of participants ($n = 39$) reported that they selectively choose the media for reading depending on the type of reading they have; they mostly use paper when they read information that should be thoroughly understood,

Table 4. Descriptive Statistics of Participants' Perceptions of Paper, Computer, and Tablet Media used for Reading Activity by Gender

Perceptions	Medium	Paper		Computer		Tablet	
		Mean	SD	Mean	SD	Mean	SD
Preference		3.43	0.62	2.81	0.58	2.55	0.78
Women ($n = 32$)		3.38	0.66	2.72	0.52	2.63	0.75
Men ($n = 15$)		3.53	0.64	3.00	0.66	2.40	0.83
Familiarity		3.57	0.58	2.87	0.45	2.34	0.79
Women		3.63	0.55	2.88	0.34	2.44	0.64
Men		3.47	0.64	2.87	0.64	2.13	0.76
Utility		3.38	0.68	2.70	0.75	2.55	0.90
Women		3.41	0.71	2.66	0.75	2.66	0.94
Men		3.33	0.62	2.80	0.78	2.33	0.82

such as class materials and journals. Regardless of gender, paper is the most preferred and familiar medium compared with computer and tablet media sources (see Table 1). Moreover, most participants reported that they do not have skepticisms of digital reading media: 61.7% of participants ($n = 29$) expressed that they do not have a bias towards digital reading media and believe that digital media-based reading enables individuals to effectively read and understand information.

Table 5. The Result of Repeated ANOVA for Objective Variables Across Paper, Computer, and Tablet Readings

	Print Reading (PR)	Computer Reading (CR)	Tablet Reading (TR)	$F(df)$	Sig.	η^2
	Mean \pm SD	Mean \pm SD	Mean \pm SD			
Pupillometry (left)	2.81 \pm 0.12	3.13 \pm 0.12	3.30 \pm 0.13	7.49 (2)	0.005 ***	0.28
Pupillometry (right)	2.84 \pm 0.11	3.58 \pm 0.12	3.81 \pm 0.16	8.60 (2)	0.000 ***	0.49
Fixation Duration	222.27 \pm 10.29	291.03 \pm 15.08	245.02 \pm 11.76	13.73 (2)	0.000 ***	0.41
Fixation Frequency	4566.14 \pm 188.51	4548.11 \pm 207.22	4178.94 \pm 117.99	3.80 (2)	0.030 *	0.14
Reading Time	136.29 \pm 9.63	128.73 \pm 11.2	125.19 \pm 86.67	0.98 (2)	0.393	0.06
Reading Comprehension	8.00 \pm 0.19	8.11 \pm 0.16	8.17 \pm 0.18	0.26 (2)	0.774	0.01

^a Statistical significant difference is indicated as *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

^b Data presented with *pupillometry* in mm; *fixation duration* in second; *fixation frequency* in counts, *reading time* in sections; *research comprehension* with scores out of 1

^c All statistical numbers were rounded up to two-decimal places, with the exception of p -values

4.3.2. Objective Variables of Reading Experience

The repeated measures of ANOVA result suggests that print, computer, and tablet readings had different eye movement activity patterns on pupillometry (left, right),

fixation duration, and fixation frequency ($p \leq 0.05$), but reading ability measures did not differ across the three types of readings ($p > 0.05$). Our hypotheses were partially validated.

The *post-hoc* results of eye movement variables showed similar results with study 1. The *pupillometry* of both eyes seem to be greater when reading from a computer and a tablet than reading from print medium ($p \leq 0.05$). However, a statistical difference of *fixation frequency* was only observed between print and tablet readings (diff = 387.20, $p = 0.050$). An interesting difference was observed in the result of *fixation duration*. In accordance with the results of study 1, longer fixation duration was observed with computer reading rather than print reading (diff = -68.77; $p = 0.000$). However, unlike the results of study 1, the difference of fixation duration was also observed between computer and tablet (diff = 46.01, $p = 0.000$), which means there was a longer fixation duration observed from computer reading than tablet reading.

Similar to the results of study 1, *reading time* and *reading comprehension* were statistically insignificant across print, computer and tablet readings. For both reading time and reading comprehension, Mauchly's test indicated that the assumption of sphericity had been accepted ($\chi^2(2) = 5.47$ and $p = 0.065$; $\chi^2(2) = 1.04$ and $p = 0.596$). However, the rmANOVA indicated no statistically significant effect of reading time and reading comprehension across three different reading media (Wilk's Lambda = 0.92, $F(2, 40) = 0.975$ and $p = 0.393$; Wilk's Lambda = 0.99, $F(2, 45) = 0.26$ and $p = 0.774$). Therefore, hypotheses 1-2 and 1-3 was not validated.

Table 6. Post-hoc Comparison of Objective Variables
Between Print Reading (P), Computer Reading (C), and Tablet Reading (T)

	PR - CR		PR - TR		CR - TR	
	diff	Sig. ($p < 0.05$)	diff	Sig. ($p < 0.05$)	diff	Sig. ($p < 0.05$)
Pupillometry (left)	-0.32*	0.076	-0.49*	0.001	-0.17	0.093
Pupillometry (right)	-0.74*	0.000	-0.97*	0.000	-0.23	0.064
Fixation Duration	-68.77*	0.000	-22.70	0.176	46.01*	0.000
Fixation Frequency	18.02	1.000	387.20*	0.050	369.18	0.072
Reading Time	7.56	0.356	11.10	0.172	3.54	0.520
Reading Comprehension	-0.11	1.000	-0.170	1.000	-0.06	1.000

^a diff = mean of condition 1 – mean of condition 2

Statistical significant differences is indicated as *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

^b PR=Print Reading, CR=Computer Reading, TR=Tablet Reading

^c Data presented with *pupillometry* in mm; *fixation duration* in second; *fixation frequency* in counts, *reading time* in sections; *research comprehension* with scores out of 1

^d All statistical numbers were rounded up to two-decimal places, with the exception of p -values

4.3.3. Subjective Variables of Reading Experience

In this research, we used five subjective variables of reading experience to investigate whether each variable differed after reading from print, computer and tablet. Hypothesis 2 assumes that the five subjective assessments—*perceived difficulty*, *perceived understanding*, *perceived confidence*, *perceived fatigue*, and *perceived immersion*—would differ across print, computer and tablet readings. In the analysis, the results showed that *perceived difficulty* was the only variable that was not statistically significant in print, computer, and tablet readings ($p = 0.407$).

Interestingly, *perceived understanding* and *perceived confidence* were only statistically significant between paper reading and tablet reading media; hypotheses 2-2 and 2-3 are partially supported. Perceived understanding and perceived confidence do not relate to the effect between print reading and computer reading. The participants' levels of *perceived understanding* of reading materials were

significantly different across three reading types ($F(2, 45) = 5.93$, and $p = 0.005$). In particular, the level of understanding on reading material was statistically significantly lower in only tablet reading (2.38 ± 0.07 and $p = 0.005$) than in print reading (2.66 ± 0.07). Moreover, *perceived confidence* on reading comprehension also differed across three reading types ($F(2, 45) = 5.90$, and $p = 0.005$). The average confidence level on reading comprehension in print reading (2.57 ± 0.08) was higher compared with the average of confidence level in tablet reading (2.31 ± 0.08 and $p = 0.005$).

Perceived fatigue and *perceived immersion* are potential variables that could be influenced by the materialistic characteristics of the presented reading media. Our result fully supported hypotheses 2-4 and 2-5 that both perceived fatigue and immersion differed across print, computer, and tablet readings; participants experienced more eye fatigue and less immersion from computer and tablet readings than from print reading. *Perceived fatigue* has a significant effect on three different readings ($F(2, 45) = 35.74$, and $p = 0.000$). The level of fatigue during reading tasks was statistically significantly lower in computer reading (2.50 ± 0.04 and $p = 0.005$) and tablet reading (2.55 ± 0.07 and $p = 0.000$) than print reading (3.04 ± 0.05).

For *perceived immersion*, the assumption of sphericity had been violated ($\chi^2(2) = 7.49$ and $p = 0.024$), and the degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity. The results showed there was a significant effect on the level of immersion while reading from print, computer, and tablet readings ($F(1.73, 79.77) = 5.43$ and $p = 0.009$). Participants perceived the levels of immersion differently across paper, computer, and tablet reading media. The levels of perceived immersion were lower in computer reading

(2.76±0.06 and $p = 0.021$) and tablet reading (2.70±0.08 and $p = 0.03$) than in print reading (2.95±0.07).

Table 7. The Result of Repeated ANOVA for Subjective Variables Across Print, Computer, and Tablet Readings

	Print Reading (PR)	Computer Reading (CR)	Tablet Reading (TR)	F(df)	Sig.	η^2
	Mean ± SD	Mean ± SD	Mean ± SD			
Perceived Difficulty	2.48±0.07	2.38±0.07	2.36±0.07	0.92(2)	0.407	0.04
Perceived Understanding	2.66±0.07	2.55±0.01	2.38±0.07	5.93(2)	0.005**	0.21
Perceived Confidence	2.57±0.08	2.45±0.06	2.31±0.08	5.89(2)	0.005**	0.21
Perceived Fatigue	3.04±0.05	2.50±0.04	2.55±0.07	35.74(2)	0.000***	0.45
Perceived Immersion	2.95±0.07	2.76±0.06	2.70±0.08	5.43(1.73)	0.009**	0.46

^a Statistical significant difference is indicated as *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

^b Each variable is rated with the highest value of 4 and the lowest value of 1

^c All statistical numbers were rounded up to two-decimal places, with the exception of p -values

Table 8. Post-hoc Comparison of Subjective Variables Between Print Reading (P), Computer Reading (C), and Tablet Reading (T)

	PR - CR		PR- TR		CR - TR	
	diff	Sig. ($p < 0.05$)	diff	Sig. ($p < 0.05$)	diff	Sig. ($p < 0.05$)
Perceived Difficulty	0.10	0.986	0.12	0.546	0.02	1.000
Perceived Understanding	0.11	0.645	0.28	0.005**	0.17	0.075
Perceived Confidence	0.13	0.424	0.27	0.005**	0.14	0.071
Perceived Fatigue	0.55	0.000***	0.50	0.000***	-0.05	1.000
Perceived Immersion	0.19	0.021*	0.25	0.03*	0.06	1.000

^a diff = mean of condition 1 – mean of condition 2

Statistical significant difference is indicated as *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

^b PR=Print Reading, CR=Computer Reading, TR=Tablet Reading

^c All statistical numbers were rounded up to two-decimal places, with the exception of p -values

Chapter 5. Discussion

The goal of this study was to examine how individuals' objective and subjective variables of reading experience differ across print and digital media (e.g., computer and tablet). In particular, cognitive workload differences across print, computer, and tablet readings were indirectly measured by objective and subjective measures. In this study, we used three eye movement measures (*pupillometry*, *fixation durations* and *fixation frequency*), two other objective measures of reading experience (*reading time* and *reading comprehension*), and five subjective variables (*perceived difficulty*, *perceived understanding*, *perceived confidence*, *perceived fatigue*, and *perceived immersion*). We conducted two different experimental studies to investigate digital natives' cognitive and behavioral reading differences across print, computer, and tablet readings. Two notable findings of our experiments were: (1) more cognitive workloads could be observed from both objective and subjective variables when reading digital media instead of print media, and (2) reading activities across print, computer, and tablet formats could be more psychological and subjective than we might think.

Research Question 1. The first main finding is that, for the eye movement patterns, we noticed two interesting points of cognitive workloads across print, computer, and tablet readings, which could be explained with three different eye movement measures: pupillometry, fixation duration, and fixation frequency.

First, more cognitive workloads were indirectly observed from digital readings compared to print reading. We assumed that cognitive workloads would occur

differently across print, computer, and tablet readings because the nature of screen reading. It could be evidenced from higher pupillometry and longer fixation duration partially observed from digital readings compared with print reading in both studies 1 and 2 ($p \leq 0.05$). Baron (2015) suggested that screen reading might distract readers from concentrated reading by taking their attention away and require more cognitive effort to process information. Such mental efforts can also be explained by the materialistic characteristics of the presented media. The characteristics of screen (e.g., screen contrast, optical strain, display quality) could make individuals impose additional cognitive efforts while understanding content, which could generate constraints during the cognitive processing of information (Mayes, Sims, & Koonce, 2001; Wästlund et al., 2005; Hou et al., 2017).

Unlikely to the result of pupillometry and fixation duration, fixation frequency was observed to be higher in print reading than tablet reading. Because fixation frequency is an indirect measure of cognitive workloads (Coral, 2011), our result yields that print reading have a higher level of cognitive workloads compared to tablet readings. However, from this result, we could demonstrate that people read more thoroughly when reading from print than digital media. In particular, people are less likely to have a focused reading on tablet than print (diff = 585.08, $p = 0.040$; diff = 387.20, $p = 0.050$, see Tables 3 & 6). This result could be explained by unfamiliarity with the medium usage. According to our data, both female and male participants reported that the computer is a more familiar device for digital reading than the tablet (see Table 4), which means they utilize computers more often for daily reading. Even though most participants have prior reading experience with print, computer, and tablet media, only 19.1% of participants ($n = 9$) use tablets as their daily reading devices while 29.8% of participants use

computer. Medium familiarity could be an important variable when understanding reading activity differences across different types of reading formats.

Since our brain function spares attention span-based spaces for more unfamiliar and newer information (Hammond, 1987), people place extra cognitive efforts when reading using unfamiliar media. Moreover, some researchers have been investigated medium familiarity and its effects on reading experience. Previous studies found a positive relationship between computer and tablet familiarities and reading comprehension. Participants with high levels of computer or tablet familiarity performed significantly better on comprehension than participants with low levels of familiarity (Chen et al., 2014). Therefore, we suggest future studies to investigate the difference between cognitive workloads and medium familiarity across reading activities on various reading formats.

Research Question 2. The first main finding is that reading activities across print, computer, and tablet formats could be more psychological and subjective than we might think; this might suggest that we unconsciously have digital skepticism. Our results from both studies 1 and 2 demonstrated that reading time and reading comprehension did not differ across print, computer and tablet readings ($p > 0.05$). However, subjective measures of reading comprehension—perceived understanding and perceived confidence—were different across print, computer, and tablet readings ($p < 0.01$). Readers from study 2 perceived that they had higher understandings of materials presented on paper and lower confidences in their comprehension of material presented on digital medium, which is the tablet. This result might suggest that young people's reading ability or literacy is not as negatively influenced as our society might concern.

Because portability and ubiquitous characteristics of digital devices have allowed us to access and read information at any time, digital generations are developing their own digital reading skills best suitable for medium types. According to our survey, 83% of participants ($n = 39$) in study 2 reported that they selectively choose the media for reading depending on the type of reading they have. Most preferred to read on paper regardless of reading materials, most participants expressed that they do not have skepticism over digital reading. Therefore, the argument that technology usage has influenced on our reading comprehension could be an overissued justification. The influence on reading ability might be less significant than our current level of concern. Therefore, an interesting future study would be an investigation of possible relationships between digital skepticism and objective and subjective differences of reading experience across print and digital media.

The second main finding is that our subjective measures also suggest that reading from digital media could be more cognitively demanding than reading from print media (see Table 8). Cognitive workloads can be indirectly measured by perceived fatigue, perceived understanding and perceived confidence. In study 2, participants perceived that the level of fatigue was higher on computer and tablet readings than print reading ($p < 0.01$). Because fatigue imposes an extra loads on the cognitive processing system and distract readers to form a cognitive mapping of information while reading (Hou et al., 2017), this result could give a possible explanation for cognitive differences between reading via print and digital media.

Furthermore, perceived difficulty is another variable that can directly affect cognitive workloads of performed activity (Brunken, Plass, & Leutner 2003). Unfortunately, our results show that participants perceived that the reading level of

difficulty of materials across media were similar ($p = 0.407$). However, perceived understanding and confidence levels could be used as indirect measures to explain cognitive differences. If participants put more mental efforts in reading digital media, then they would be more likely to have less confidence in their understanding. An interesting point is that the perceived understanding and confidence only differed between print and tablet reading ($p < 0.01$), which denotes that participants experienced more mental efforts when reading on tablets. Taken together, people might experience more mental efforts when reading on digital formats than on printed formats, but the tablet could be an inappropriate medium for daily or academic reading activities.

5.1 Research Contribution

This research has two distinctive contributions to existing literature. First, we investigated cognitive workloads and skimming patterns across print, computer and tablet readings with eye-movement analysis of readers. Our results partially confirm the previous studies suggesting digital reading might be related with more cognitive workloads and skim reading (DeStefano & LeFevre, 2007; Hillesund, 2010). Our results could make a meaningful contribution to previous literatures because there have been very few research comparing cognitive aspects of reading experience across print and digital media with eye movement analysis. Furthermore, the present work is designed to be one of few eye-tracking research to consider A4-size page length of texts for reading activities across different types of reading formats. There should be more print and digital reading comparison studies examining differences of reading activities on different types of reading formats

when reading lengthy passages. Interesting result could be observed from reading tasks with longer lengths of texts, which might introduce long-term interaction variables associated with different types of reading formats.

Second, this research is one of the few studies examining the effect of reading media using within-subject experiment design and investigating such differences utilizing both computer and tablet media. Most comparison studies of print and digital media are based on between-subject design. If this study validates the phenomenological differences between print, computer and tablet readings, this would make a meaningful contribution to the results of previous studies because of the individual differences on reading experiences across the reading media. Moreover, this study also observes and provides insights into how multiple digital media sources (e.g., computer and tablet) differ from print media. Many studies of digital reading deal with reading e-books or e-resources from computer environment (Jones & Brown, 2011; Siegenthaler et al., 2011; Rainie & Duggan, 2012). As the use of the tablet for reading is becoming more common, more studies should investigate the influencing factors of tablet reading and the differences between print and tablet or between computer and tablet.

5.2. Limitations and Future Directions

Despite our contribution to previous studies comparing reading experience across print and digital media, this study has several limitations. First, our within-subject experiment design may have a carryover effect. To reduce the effect size, our experiment randomized the orders of three reading conditions and nine reading materials; however, any carryover effect would exist during the experiment. To

examine individual differences when reading from paper, computer, and tablet, we intentionally used such experimental design. We believe that it makes our study distinctive from many of the previous comparison studies of print and digital readings. We suggest future studies to carry out the within-subject experimental design to observe the differences in reading activities across print and digital media with the repeated measurements of the same individual.

Second, inconsistent experimental materials for tablet readings were utilized for studies 1 and 2. Because the sizes and resolutions of screen display could influence test performance (Bridgeman, Lennon, & Jackenthal, 2003), the results of our study, especially eye movement analysis, could be influenced by such materialistic differences of tablet readings. Moreover, future studies should be aware that eye movement measures could be easily influenced by factors such as variations in texts and typographic, letter spacing, and line length variables (Jacobson & Dodwell, 1979; Kolars, Duchnick, & Ferguson, 1981), and between-reader variabilities could exist. For example, as text becomes conceptually more difficult, fixation duration increases, saccade length decreases, and the frequency of regressions increases (Jacobson & Dodwell, 1979).

Third, our study relies on a sample of young college students in South Korea, known as digital natives, who are very familiar with reading from digital media. According to several reports regarding reading and digital literacy, Korean adolescents have ranked the highest in print and digital reading assessments in the world (Mendelovits, Ramalingam, & Lumley, 2012; Organization for Economic Co-operation and Development, 2016). Our results could not reflect the population of young adolescents with low digital literacy. Age differences and digital literacy levels could be important moderating variables that have a capacity to impact

reading experience on print and digital media. We suggest future studies investigate a more diverse population to replicate the results of this study. Making a comparative study of individual variables, such as age, educational backgrounds, and literacy levels, on reading experiences across digital media would also be interesting. Moreover, because of the nature of the sample used in this study, we cannot generalize the findings to other demographic types. This study only reflects the characteristics of reading experiences of Korean young adults. The results do not generalize to other cultural or geographical areas. Therefore, we also suggest that future studies explore the different tendencies of reading experiences across print and digital media in diverse cultural context, which would provide a challenging but interesting study.

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국문 초록

오늘날 모바일 기기 활용이 대중화되면서 사람들의 독서 방식이 변화하였다. 기존의 종이 이외에도 컴퓨터, 태블릿과 같은 디지털 매체를 활용한 독서가 일상화되고 있다. 디지털 독서가 일상 속에 스며들면서 사람들의 읽기 능력, 독서에 대한 선호도 및 태도에 중대한 영향을 미칠 수 있다는 우려가 커지고 있다. 이를 고려하여 많은 연구자는 매체 별 읽기 경험이 독해력에 미치는 영향을 조사하기 위해 다양한 연령대를 대상으로 종이 읽기와 디지털 읽기의 비교 연구를 진행하였다. 읽기는 인간이 학습하는 데 있어 매우 중요한 역할을 수행하는 인지 활동이라는 점에서, 매체 환경의 변화가 인지 및 읽기 능력에 미치는 영향을 탐구하는 것은 시사점이 있을 것이다.

본 연구는 종이와 디지털 독서에서의 읽기 경험 차이를 탐구하기 위해 종이, 컴퓨터, 태블릿 전반에 걸친 읽기 실험을 진행했다. 구체적으로, 짧은 글 읽기에서 나타나는 매체 별 인지 부하의 차이점을 조사했다. 인지 부하를 측정하기 위해 실험참가자들의 시력 추적 데이터, 읽기 시간, 독해 점수 및 5 개의 심리적 변수를 활용하였다. 본 연구는 2 개의 실험을 한국의 대학교 학부와 대학원에 재학 중인 학생들을 대상으로 진행하였다. 두 실험에서 학생들은 안구 추적 장치를 착용하고, 종이, 컴퓨터 및 태블릿 매체를 통해 A4 용지 한 장 분량의 짧은 지문을 읽고, 독해력 측정 시험을 진행한 후 자기평가 설문지에 응답하였다.

본 연구의 두 가지 주요 결과는 다음과 같다. 첫째, 종이 읽기보다 디지털 매체에서 더 높은 인지 부하가 발생하는 것을 관찰하였다. 특히, 태블릿 읽기는 인쇄 및 컴퓨터 읽기보다 더 많은 인지 부하를 요구하며, 짧은 글을 읽을 때 부적절한 읽기 매체일 수 있음을 보여주었다. 둘째, 종이, 컴퓨터 및 태블릿 읽기 활동은 우리가 생각하는 것보다 더 심리적이며 주관적일 수 있다. 독서 시간과 독해력에 차이는 없었지만, 학생들은 디지털보다 종이에서 글을 읽을 때 이해력이 더 높았으며 독해 평가 결과에 대한 자신감이 더 높다고 느꼈다. 본 연구 결과는 디지털 매체를 활용한 읽기 활동은 더 높은 수준의 인지 부하를 요구하지만, 실제 독해 능력에 대한 영향은 미미할 수 있음을 시사한다. 따라서, 오늘날의 디지털 사회에서는 독자가 자신의 선호도와 독서 목적에 따라 매체를 선택하여 읽기를 하는 것이 바람직하다.

주요어 : 종이 읽기, 디지털 읽기, 읽기 행동, 인지 부하, 시선 추적 분석

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