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Digital Reading vs. Paper Reading: Does Mind Wandering Mediate Comprehension Differences?

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Digital Reading vs. Paper Reading: Does Mind Wandering Mediate Comprehension Differences?

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DEDICATION

This dissertation is dedicated to my wife, Lindsey Permar. Finishing my doctorate was a team effort, and it would not have been possible without her patient and selfless support. Furthermore, many of my best ideas came from discussions with her about knowledge, reading, and education. Thank you.

ABSTRACT OF THE DISSERTATION

Digital Reading vs. Paper Reading: Does Mind Wandering Mediate Comprehension Differences?

by

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Doctor of Philosophy, Graduate Program in Education
University of California, Riverside, June 2018
Dr. Lee Swanson, Chairperson

Research on reading from digital devices has generally shown a decline in comprehension performance when reading from a digital screen as opposed to reading from paper, under certain conditions—namely, when texts are longer and when comprehension is measured as deeper-level understanding of text, relying on higher order reading skills rather than merely measuring recall. The present study attempted to replicate previous findings, and to investigate whether comprehension declines are mediated by increased mind wandering when reading from a digital medium compared to when reading from paper. A sample of 169 high school students was given a text to read, either on paper or on a digital tablet. Following the reading, subjects were given two reading tests: an inference-based comprehension test and a recall test. Mind wandering was measured by using a mind wandering probe adapted from Hollis & Was (2016). I did not replicate previous findings: I found no significant relationship between reading condition and inference-based comprehension. Further, no relationship was found between reading condition and mind wandering (i.e., there was not more mind wandering in the digital condition, as I had hypothesized). However, mind wandering was significantly related to inference-based comprehension, and a novel approach to capturing mind wandering in a group setting was successfully implemented. I discuss implications of these findings and possible directions for future research.

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CHAPTER I

INTRODUCTION

We now live in a world that is constantly connected, "plugged in," to limitless sources of both digital information and digital distractions. In the few seconds after a person has a question, he or she can instantaneously find the answer on a computer, tablet, or even from the phone in their pocket. The many implications of this new digital environment are largely unknown. This new digital world raises countless questions in a variety of areas—perhaps most importantly in the areas of education. How we learn and read from these devices remains a largely open question.

As more and more parents purchase digital devices for their children, and as more and more schools implement 1:1 tablet and computer programs, the question of how reading occurs from a digital platform versus the old and familiar paper text is in dire need of being better understood. This question is a complicated one, however, since reading itself is a multifaceted cognitive process.

A series of studies that have compared reading from screens to reading from paper have shown that when reading lengthy texts, screen-reading is associated with declines in comprehension (Mangen, Walgermo, & Bronnick, 2013; Ackerman & Goldsmith, 2011; Wastlund, Reinikka, Norlander, & Archer, 2005; Flanagan & Kaufman, 2016). It is important to note that in this line of questioning the reading referred to is *linear* reading, although not all authors make this distinction explicit. Hypertext function of digital devices is not included in such studies. In the past, researchers hypothesized that screen reading could add extra cognitive load due to unfamiliarity with the medium, leading to less working memory availability for text comprehension (Mayes, Sims, & Koonce, 2001). But this explanation is less convincing today, when use of e-readers is widespread. Recently, Flanagan and Kaufman (2016) demonstrated that comprehension declines in digital reading conditions (relative to a paper control) were only found when comprehension was defined as understanding that relied on inference-making. Hollis and Was (2016) suggested that when students are engaged in a learning task involving technology, the mind may wander to task-unrelated tech activities (e.g., checking Facebook). The purpose of the present study is to ascertain whether the decreased reading comprehension performance on digital devices that has been found in past studies is related to this increase in mind wandering while learning from a digital device. Of particular interest is whether decreases in reading comprehension are related to mind wandering associated with the digital environment that students are used to interacting with on their devices (i.e., Facebook, Instagram, Twitter, etc.).

This study was designed to replicate previous findings that show that digital reading is associated with declines in comprehension when texts are longer and when comprehension is defined as deeper level understanding relying on inference-making, rather than mere recall. I then wanted to investigate whether mind wandering while reading mediated the effects of reading medium—screen or paper—on reading comprehension. In the present study, the digital screen condition was from a tablet (Acer Chromebook). The following research questions were pursued:

1. Is the digital reading condition associated with declines in reading comprehension?

2. If so, does TUT mediate differences in comprehension between the digital and paper reading conditions?
3. Is a significant amount of the TUT in the digital condition related to technology-related thoughts?

While the studies mentioned above have, in fact, shown declines in comprehension when people read from digital texts compared to reading from paper, it is important to note that this is only half of the story. The overall trend in the literature that investigates reading from digital screens has been decidedly mixed. Many studies have *also* shown that reading from screens versus paper appears to make no difference whatsoever (Keene & Davey, 1987; Porion, Aparicio, Megalakaki, & Baccino, 2013; Singer & Alexander, 2017a). Singer and Alexander (2017b), note that a major issue in this literature is a failure among researchers to adequately describe measures, procedures, and definitions of reading. As a result, the mixed nature of the results becomes even more muddled for current researchers trying to expand the literature. What is clear, based upon both Singer and Alexander's recent systematic review (2017b), and a meta-analysis conducted as part of the present study, is that a major difference in findings appears to hinge upon both measure type and text length. These two moderators of the effects of digital reading, when properly contextualized within cognitive theories of reading, have guided the present study to focus on mind wandering as a potential mediator of the negative effects of reading longer texts on a digital device.

CHAPTER 2

LITERATURE REVIEW

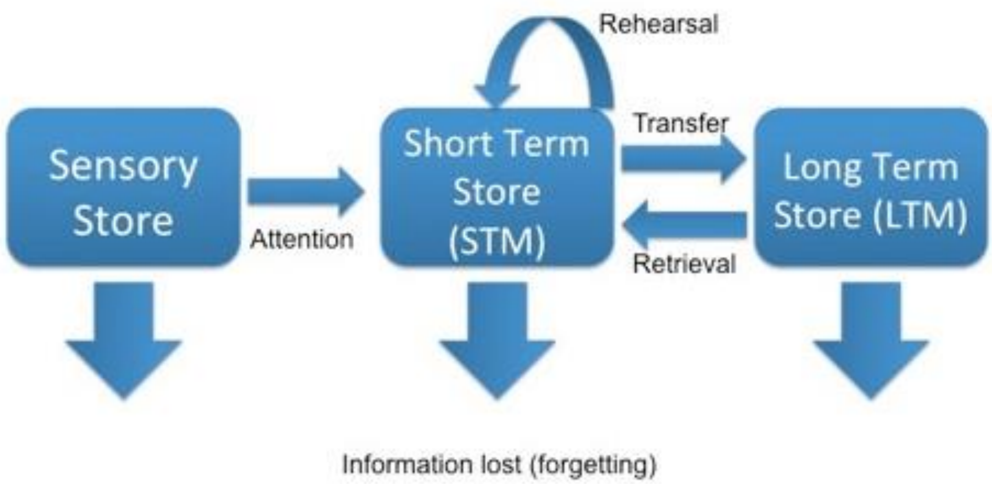
The theoretical rationale for this study is grounded in several overlapping theoretical contexts. To properly understand how and why this study was designed as it was, it is necessary to understand the basics of the following theoretical frameworks: Baddeley's *working memory model* (2000), reading processes—in particular, Kintch's *construction integration model* (Kintsch, 1988)—and theories related to mind wandering. Only after understanding each of these theories and mental processes is it possible to contextualize the research literature on digital reading within a well-organized cognitive processing framework. This chapter will first discuss theories of working memory, text processing, and mind wandering—and how they interact with one another—and then move on to an overview of the research literature on comparative studies that investigate reading from paper versus reading from digital screens. This last section also includes meta-analytic procedures to more accurately unpack the varied findings in this line of inquiry.

Working Memory System

Atkinson & Shiffrin (1968)

Models of working memory (WM) describe how new information is temporarily stored, organized, and encoded into long-term memory (LTM). Atkinson and Shiffrin's multi-store model (1968) proposed that memory consisted of three components: a sensory register, short-term memory (STM), and long-term memory (LTM). In this model, information passes through each store in a linear fashion. Perceived information enters sensory memory, where salient items are attended to and moved into STM. Items in STM can be recalled directly from the short-term store, but only for a period of approximately 18-20 seconds if not rehearsed. Items can be kept in STM for a theoretically unlimited amount of time, according to this model, through a rehearsal process. Furthermore, this rehearsal process is the means by which items become encoded into long-term memory (LTM). According to this model, the length of time that items are rehearsed determines the strength of the memory trace in LTM.

Figure 1. Atkinson & Shiffrin Model (1968)



Evidence for Separate STM and LTM Systems

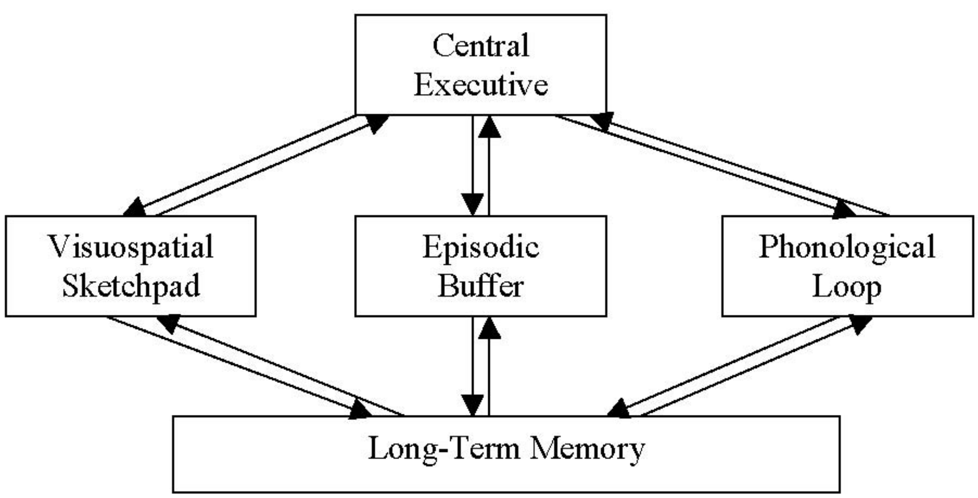
While this model was incomplete, it changed the way that memory had previously been characterized—as a single, unitary system. Atkinson and Shiffrin's two-store model provided a logical account of primacy and recency effects. Primacy and recency effects have to do with serial positions of items in a list. Murdoch (1962) established serial position effects by asking subjects to memorize word lists of varying lengths, followed by a free recall task. Results from this study demonstrated that the probability of recalling a word from a list depended upon its serial position—with words at the beginning and end of the list more likely to be recalled than items in the middle. Murdoch used the Atkinson and Shiffrin model to explain these results: items from the beginning of the list have been rehearsed longer, and are therefore sufficiently encoded into LTM to produce more accurate recall; items at the end of the list are recalled due to the fact that they are still in STM. Items in the middle tend to be forgotten because they have not been sufficiently rehearsed in working memory to have been encoded in LTM, and they are no longer present in STM. In the present study, primacy and recency effects were taken into account when creating the recall measure, which utilizes passages from both the first and last thirds of the reading used in the experiment.

The Atkinson and Shiffrin model was highly influential to memory research by providing strong evidence in favor of two separate memory systems. In addition to primacy and recency effects, further evidence suggesting separate systems comes from amnesia patients—in particular, the famous H.M. The fact that H.M'.s short-term memory was intact, but he was unable to encode new memories into LTM, clearly indicated two separate systems. However, the Atkinson and Shiffrin model is a bit too simple—especially in its account of what STM actually is.

Baddeley's WM Model

Baddeley and Hitch (1974) built upon the Atkinson and Shiffrin model by transforming their unitary short-term store into a dynamic *working memory* (WM) system, composed of multiple sub-systems (i.e., a central executive and two slave systems). In their model, information enters WM through the sensory register (just like in Atkinson and Shiffrin). Once in WM, a central executive controls the processing of information. In the original (1974) formulation of the model, the central executive controlled two *slave systems*: a phonological loop and a visuo-spatial sketchpad. The phonological loop deals with verbal information, and contains two subcomponents: a phonological store and an articulatory control. The visuo-spatial sketchpad stores visual and spatial information. Later, Baddeley (2000) added an episodic buffer to the model. The episodic buffer accounts for some of the more complex aspects of reasoning that could not adequately be accounted for by the previous model. It stores information in a multimodal code that binds information from the other two slave systems together with relevant information retrieved from LTM. They are bound together into a "unitary episodic representation." In this way, the updated model can better account for processes related to the integration of information.

Figure 2. Baddeley's Working Memory Model



Baddeley's various components explain a great deal of our ordinary experiences. The functioning of the phonological loop, for example, helps explain the ways that people read and comprehend language, and the visuospatial sketchpad explains how we navigate through space. Furthermore, there is a vast amount of empirical data supporting Baddeley's WM model. Much of Baddeley's research has focused on the phonological loop component of his model, and the following experimental phenomena are well-accounted for by his conception of the phonological loop: the phonological similarity effect, the word length effect, articulatory suppression, and irrelevant sound effects (Baddeley, 2012).

A *phonological similarity effect* was first noticed by Conrad & Hull (1964), who "noted that even with visual presentation, memory errors resembled acoustic mis-hearing errors (e.g., *v* for *b*), and that memory for [acoustically] similar sequences… was poorer than for dissimilar" (Baddeley, 2012). This phenomenon provides evidence for information being coded into STM as an acoustic code (Baddeley, 2012).

The *word length effect* refers to the idea that longer words tax the phonological system more heavily than shorter words. Since the loop relies on a sub-vocal rehearsal to maintain items in the phonological store, longer words should take longer to rehearse, leading to decay and loss of more items from memory than for lists of shorter words. This was demonstrated by Baddeley, Thompson, and Buchanan (1975) in a study that compared participant recall on lists of five short, one-syllable words to recall on lists of five words of longer length (up to five syllables). They found that recall declined systematically as a function of word-length. Articulatory suppression is highly related to the word length effect: if recall depends upon subvocal rehearsal, then suppressing rehearsal should eliminate the word-length effect. This appears to be the case: subjects whose rehearsal process is taken up by a task, such as repeating the same word over and over, recall both short-word lists and long-word lists with more or less the same accuracy, but overall accuracy declines (Baddeley, et al., 1975). The phonological nature of information encoding and storage is extremely important—and has huge implications for how we understand reading and how reading works; reading processes cannot be properly understood without understanding the working memory system.

What Baddeley's model added to the equation was that it took the oversimplified, yet elegant, model of Atkinson and Shiffrin and zoomed in on the unitary store of STM and decomposed it into three (and later, four) functional parts. Baddeley's model focuses on the fact that there is a separate system from LTM—one that does *more* than just store information for short periods of time. Hence, *working* memory. Working memory, according to Baddeley, is where new information is stored, combined with relevant information from LTM, and then manipulated to create new knowledge.

In the next section, reading processes will be explained in connection to Baddeley's (2000) working memory model: lower-order reading processes construct meaningful models of a text within WM that are then encoded into LTM.

Reading Processes

What is Reading?

In Thorndike's *Reading as Reasoning* (1917), he argues that reading is a complex series of procedures that must coalesce in the right way to produce a proper understanding of a text, and that, fundamentally, it is more akin to reasoning, rather than a simple matter of decoding words that would then somehow automatically map onto meanings in the mind. Thorndike comes to this conclusion by analyzing mistakes in children's reading comprehension, based upon a series of paragraph readings followed by answering, in free form, a series of comprehension questions about the paragraphs.

One of Thorndike's (1917) most important insights was to notice that children's mistakes did not fit neatly into well-defined, easily understood, categories of wrongness. Rather, they displayed a "variety that threaten[ed] to baffle any explanation" (p. 326). By analyzing the mistakes of two hundred sixth graders, Thorndike came to the conclusion that the mistakes made were mainly due to underpotency and overpotency of particular words. His explanation is grounded in a theoretical framework in which Thorndike claims that correct reading relies on three principles. For correct reading to occur, the following conditions must be met: "(1) each word produces a correct meaning, (2) each such element of meaning is given the correct weight in comparison with others, and (3) the resulting ideas are examined and validated to make sure that they satisfy the mental set or adjustment or purpose for whose sake the reading was done" (p. 326). Of the mistakes made by Thorndike's 6th graders, it seems clear that the last two of these principles were the most clearly violated principles leading to comprehension errors. The students' initial weights assigned to particular words were often wrong, leading to both semantic and inferential errors. For example, two subjects believed that the first paragraph, which was about a school's absence policies, was, in fact, about illness. This was due to an over-potency of the word "illness" and other vocabulary that had to do with being sick (e.g., “ill,” “contagious,” “disease”). Further, that students make mistakes based upon over and under-potency suggests that they have not examined and validated their initial conclusions.

Thorndike’s findings were, in many ways, similar to those of Brown and Smiley (1978) just over sixty years later. In a series of three experiments, Brown and Smiley investigated the various reading strategies used by college students, juniors and seniors in high school, and fifth through eighth graders. Among their findings, they found that children below 7th grade in their sample seemed unable to differentiate between more and less important parts of the text. In Thorndike’s terms, different parts of the text were assigned the wrong weights, hindering effective use of time while studying, and overall comprehension.

Based upon what we know now about reading processes, Thorndike’s initial claim that reading can be viewed as reasoning is supported by much of the most current research in reading, as is his conclusion that students likely often fail in their studies because, after being given readings on a topic, “they never understood them”—as opposed to having properly understood and then forgotten (p. 331). However, in this same passage, Thorndike also comments that these failures in comprehension are also clearly not due to an inability to organize properly understood facts. Here, Thorndike seems further off the mark than in the previous two conclusions, for more recent research has revealed that understanding and organization are, for the most part, the same thing.

Thorndike began his work by providing a definition what reading comprehension entails, and his definition is more or less consistent with current definitions used in educational research. In the RAND Corporation's 2002 report, *Reading for Understanding,* reading is defined as "the process of simultaneously extracting and constructing meaning through interaction and involvement with written language" (Snow, 2002). Theories of reading can largely be divided among those theories that deal with decoding, and those that deal with "meaning-making" (Lonigan, 2015). When Thorndike discusses reasoning with a text, what he is talking about is various forms of inference drawn from the text. In order to get to the point where a reader can make an accurate inference from the text, each layer of processing must be working simultaneously in proper form. The following discussion will outline research on the various effects of different levels of text processing, and how they affect overall understanding—beginning with vocabulary and working up to higher-order skills such as inference, prior knowledge, and comprehension monitoring.

Lower Order Reading Processes

Having the vocabulary necessary to understand a text is the first necessary step to understanding. According to Nagy & Scott (2000), if less than 90% of the words in a text are known, it is unlikely that someone will be able to accurately understand the text. Indeed, it should be of little surprise that previous studies have found that vocabulary skills at younger ages predict higher-level comprehension at older ages (Adlof, Catts, & Lee, 2010).

Semantic processing is related to vocabulary but also deals more generally with word meanings that are stored in schemas that include various forms of a word, different meanings (in cases of words with more than one definition), and connections between words—synonyms, antonyms, words in the same of any number of categories, etc. Perfetti's (2007) lexical quality hypothesis claims that deficient lexical networks will cause less-effective retrieval of word meanings. A person with a poor lexicon may recognize a word right away, but it may take them a while to process the relevant meaning in context, slowing down the reading process and interfering with higher order comprehension processes. Findings in adults show that those with poor reading comprehension tend to be slower to access word meanings (Landi & Perfetti, 2007). Numerous findings in children support the notion that poor reading comprehension is at least in part due to deficient lexical networks. Nation, Marshall, & Snowling (2001) found that poor comprehending children were slower to name pictures with low frequency names than good comprehenders were. Additionally, comprehension ability is positively associated with a child's ability to create lists of words that are semantically related (e.g., in the same category of some sort) (Nation & Snowling, 1998).

Syntactic processing is the next process in the hierarchy of reading processes. Some studies have shown that syntactic awareness is positively related to reading comprehension (Nation & Snowling, 1998). Cain (2007) showed that syntactic awareness becomes unimportant in predicting reading comprehension in children once one controls for vocabulary, working memory, and grammar—suggesting that a meta-awareness of syntax is unimportant in predicting reading comprehension. However, syntax overlaps so much with these other constructs that it is hard to imagine how syntax is not already captured by measures of grammar and working memory.

Building Meaning: Higher Order Reading Processes

The current study is informed by Kintsch's (1988) construction-integration model of text comprehension, first outlined by Van Dijk and Kintsch (1983) in *Strategies of Discourse Processes*. Based on the above discussion of reading processes, it should be clear that comprehension is a multifaceted process that relies on multiple sub-processes working in concert in order for readers to accurately understand a text. While lower-order processes are simultaneously decoding and recognizing words, putting them together with other words to form meaningful phrases, and processing syntactic information to make sense of a text's basic meaning, the overall structure of the text is being "built" in a reader's long-term memory. These lower-order processes correspond to Van Dijk & Kintsch's surface-form and textbase levels of textual understanding (1983). Surface form is essentially the words as they appear on the page, and corresponds to orthographic processing (word recognition), and any processes below this (for example, phonological and morphological processing, and grapheme-phoneme mapping that occurs to decode novel words that a person may not know). The next level, textbase, refers to the basic meaning of the text—a series of semantic propositions that have yet to be constructed into a meaningful whole (Lonigan, 2015). The final layer of Van Dijk and Kintsch's model is the *situation model,* wherein readers are mentally representing the order and layout of the "situation" of the text. This could mean forming a mental timeline with visualizations of characters and events in a narrative text, or the creation of new semantic networks of knowledge when reading an expository text. Accurately understanding texts relies upon successful marshaling of these higher order processes so that an accurate situation model of the text is created. In terms of comprehension, poor creation and maintenance of the situation model would result in a failure to understand the main idea and a failure to draw proper inferences.

Indeed, the creation of an accurate situation model relies on several layers of inference-making on the part of the reader to produce *text coherence.* There are two levels of text coherence: *local* and *global* (Graesser, Singer, and Trabasso, 1994). Local coherence has to do with linking together the various adjacent elements of the text-base to preserve meaning across sub-sections of the text. An example of this would be resolving anaphora such as in the following example: *Gwen likes to read about dragons. So does Max.* In this example, *does* is a stand-in for *read about dragons*. This intra-textual inference-making—if done successfully—results in local coherence. Global coherence refers to linking meanings from various parts of the text to the meaning of the text as a whole, and also to one's prior knowledge.

Another way of thinking about these two levels of inference-making (*local* and *global*) would be to put them in the context of Baddeley's working memory (WM) model (Baddeley, 2000). The processes behind local coherence would be operating within the WM slave-systems. That is, linking meaning from one sentence to the next is a process whereby all of the constituent parts of that process are going on within WM. Global coherence requires the reader to link the contents of WM to either the situation model of the text or to pre-existing knowledge—both of which are in long-term memory (LTM) (Lonigan, 2015). From an assessment point of view, test items on a reading assessment would tap text coherence if they asked about the main idea or asked test-takers to draw inferences from the text. Recall, on the other hand, does not require any meaningful text coherence—a student may recall the presence of a particular word or isolated idea from the text without truly having understood the meaning of the reading. Further, longer texts require more effort on the part of a reader in order to create and maintain text coherence. The longer a text, the more difficult it becomes for a reader to construct an accurate situation model. If readers do not adequately maintain attention to the reading task, then the situation model's accuracy will decline and comprehension will suffer. Theoretically, then, it makes sense that mind wandering would cause declines in comprehension by interrupting the process of text-coherence, resulting in an incomplete or inaccurate situation model of the text.

Mind Wandering

Mind wandering is typically characterized as "the interruption of task-focus by *task-unrelated thought"* (TUT) (Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013). It is best understood as a failure of executive control processes to keep cognitive resources focused on the relevant task, and, as a result, attention shifts to other thoughts that are unrelated to the task at hand. There are four working hypotheses that seek to explain the phenomenon of mind wandering: the *current concerns hypothesis, the decoupling hypothesis, the executive failure hypothesis,* and *the meta-awareness hypothesis* (Randall, Oswald, & Beier, 2014). The decoupling hypothesis concerns itself with explaining the *maintenance* of mind wandering, as opposed to the conditions that bring about the onset of task-unrelated thought. Each of the other three hypotheses deals with the onset of task-unrelated thought, and all of them are relevant in understanding mind wandering during academic activities—including reading. The current concerns hypothesis states that a shift to task-unrelated thought occurs when cognitive resources are diverted from the task at hand and become devoted to a person's most salient personal concerns. Thus, a person's attention shifts to TUT when the distracting thoughts are believed to be more rewarding than the task at hand (Smallwood, 2013). The executive failure hypothesis looks at the shift to TUT from a slightly different perspective, focusing instead on the fact that mind wandering occurs due to a failure of executive control as a result of the "intrusion of task irrelevant thoughts" (Randall, Frederick, & Beier, 2014). One could think of the executive failure hypothesis as a failure to inhibit, whereas the current concerns hypothesis seeks to explain *why* the failure of executive control occurs. The third hypothesis that deals with the onset of TUT is the meta-awareness hypothesis. This hypothesis states that individuals who possess superior monitoring capabilities are less susceptible to mind wandering because they are able to inhibit TUT after recognizing that their thoughts have shifted from task-related to task-unrelated thought. Together, these three hypotheses work together to explain the onset of mind wandering. The current concerns hypothesis focuses on the motivational factors behind mind wandering, while executive failure explains the mechanism behind the mental shift to TUT. The meta-awareness hypothesis is related to the executive failure hypothesis in the sense that it provides a more specific subset of executive control that is failing, in this case, monitoring—and, more specifically, in the case of reading, comprehension monitoring.

The present study utilizes the current concerns hypothesis and the executive failure hypothesis to explore mind wandering during reading. Previous research has found that mind wandering negatively impacts reading comprehension (Smallwood, McSpadden, & Schooler, 2008). Mind wandering is thought to harm reading comprehension due to its interference in the creation of a coherent situation model of the text (Smallwood, 2011). Smallwood, McSpadden, and Schooler (2008) demonstrated that the creation of an effective situation model is most severely limited when mind wandering occurs early in a narrative, and at moments in a text when critical information is revealed. This supports the notion that mind wandering harms comprehension due to its interference with the construction of a situation model. Missing key information early in a story makes it more difficult later on to construct a meaningful model of the text—because one does not know what happened earlier. The same logic would follow for expository reading, though the placement of the mind wandering (early versus late in the text) would, theoretically, not be as critical.

Feng, D'Mello, and Graesser (2013) found that mind wandering predicted negative comprehension performance for difficult, but not for easy texts. In other words, if it was "easy" to construct a situation model, then subjects *could* mind wander without it harming their understanding. Only when the task-demands reached a sufficient level of difficulty did mind wandering predict a decline in comprehension.

Further research has demonstrated that working memory capacity (WMC) is negatively related to mind wandering while reading, with subjects with lower WMC mind wandering more than those with high WMC (Unsworth & McMillan, 2012). This makes logical sense, especially as it relates to the executive failure hypothesis. People with higher WMC would be less likely to experience executive failure due to possessing superior executive control processes.

Interest, motivation, and prior knowledge also predict mind wandering—and these three constructs are related to one another. Students with more prior knowledge tend to be more interested in readings they know something about, which leads to higher motivation. Together, this higher motivation and knowledge-base seem to help subjects stay on task while reading, which leads to higher comprehension (Unsworth & McMillan, 2012).

Mind Wandering Due to External Stimuli

An important aspect of the current study that differs from other studies of mind wandering while reading is that I was interested in the effects of environmental stimuli disrupting task-related thought and leading to mind wandering. Much of the mind wandering and reading literature focuses on mind wandering being driven by *internal thought* and ignores environmental correlates of such thoughts. It is, nonetheless, understood by researchers in this field that the disruption of task-related thought can derive from internal distractors (e.g., personal concerns) *or* from environmental stimuli (McVay & Kane, 2012). A recent study by Hollis and Was (2016) found that students engaged in an online video learning task who mind wandered did so 29% of the time due to social media and technology-related distractors. Often, students reported that their task-unrelated thought was related to "thinking about or using another technology"—for example, "texting" or "checking Facebook." This is interesting because they did not actually *engage* in the distracting behavior. Rather, their impulse to engage in the behavior led to thoughts about that behavior that had to be inhibited in order to maintain focus on the task at hand. Indeed, enough subjects sufficiently failed to inhibit these thoughts that they were captured by a mind wandering probe. Thus, it could be the case that the very presence of the distractions inherent to a digital device may lead to a kind of cognitive "assault" on a person's executive control mechanisms—making it hard to maintain sustained focus on an extended and cognitively demanding learning task like reading a long, difficult text. The digital environment of laptops and tablets may be so distracting to students because they are habituated to using these devices for purposes other than academic tasks. For example, students may be so accustomed to rapidly task switching between different social media, email, etc., that they find it hard not to think about these activities when engaging in other tasks on the same devices—especially tasks that require vigilance and sustained attention.

Declines in comprehension associated with both reading medium *and* mind wandering tend to be of longer and more difficult texts (Mangen, et al., 2013; Feng, D'Mello, & Graesser, 2013; Ackerman & Goldsmith, 2011). It seems, therefore, that text length and difficulty are important factors that may interact with the reading medium to create a difference in comprehension. These texts require more executive control in order to construct, maintain, and update the situation model to keep them accurate. An accurate situation model predicts comprehension (Smallwood, et al., 2008). Therefore, it seems only natural to merge the research on digital reading with the research on mind wandering while reading. Perhaps there is a decline in comprehension on digital devices when reading longer and more difficult texts because more mind wandering occurs when reading from digital media than when reading from paper. If this is the case, then it would explain the declines in comprehension seen in the studies presented above. It also may help further explain Flanagan and Kaufman's finding regarding the difference between concrete and inference-based performance. A better situation model would likely lead to an increased ability to draw inferences, but would not matter as much for concrete details.

Effects of Reading Medium on Comprehension

Several recent studies have shown that digital devices are related to declines in reading comprehension when compared to reading the same texts on paper (Mangen, et al., 2013; Ackerman & Goldsmith, 2011; Wastlund, et al., 2005). On the other hand, other studies have found no difference between the two conditions (e.g., Margolin, et al., 2013; Singer & Alexander, 2017). It is important to keep in mind that in all of these studies, the digital texts have been rendered as simplified as possible—often they are simple PDF documents and they never have digital enhancements. The rationale for this decision is that introducing digital enhancements would introduce confounds to the experiments, rendering any findings somewhat tricky to discern. Further, much of what is read on digital screens *is*, in fact, devoid of enhancements, so it is worth studying in this manner in order to get a baseline understanding of how digital text is (potentially) processed differently from paper text. The present study will follow the literature in this regard.

The mixed results of the experimental literature on digital reading merit a closer look at the differences between these studies. Of the comparative studies that have investigated digital reading, some have specifically targeted cognitive processes that could potentially moderate reading processes differently depending on the reading condition (Swanson & Trahan, 1992; Mayes, et al., 2001). Working memory capacity appears to be an important potential moderator. Some researchers have claimed that reading from digital devices is more difficult due to increased mental workload (Mayes, et al., 2001). Most of these studies, however, were conducted on desktop computer terminals that were set up for the experiments—only Mangen, et al. (2013) used computer terminals that were typically used by the participants. Kaufman and Flanagan (2016) used 2nd generation iPads, which were not the students' own devices, but with which all of the students were familiar. Students' lack of familiarity in the majority of these studies would likely increase the task demands on participants' working memory, which would result in the declines in comprehension that we see. However, this gets somewhat confusing as time goes on. In past studies, it is sensible to assume that cognitive demands are higher due to the difficult nature of scrolling using a mouse and scrollbar on the side of the screen. But nowadays, scrolling is simply a matter of swiping up and down or side-to-side on the screen—it is difficult to imagine how this task is more demanding than turning a page in a book.

It is possible that for people who have not regularly use digital devices (as in many studies conducted in the past), working memory is impaired and comprehension suffers when reading from a digital screen. However, this explanation is becoming less tenable as technology use becomes more and more ubiquitous. It is also less useful: people simply do not go around reading on unfamiliar devices. Students and others read from digital devices that they use on a daily basis for a variety of purposes, and these varied purposes result in varied intellectual contexts that contain a wide range of cognitive demands. In the present study, I attempted to recreate circumstances that are more realistic, and mirror those set up by Flanagan and Kaufman (2016). It is simply of more practical importance to assess the digital conditions that students actually use while engaged in learning tasks. Contrary to past studies, I assume that familiarity with the digital environment leads to more distractions when reading from a digital device. Indeed, Flanagan and Kaufman (2016) recently demonstrated that the high levels of familiarity that people now have with digital devices might actually be bad for certain types of comprehension because familiarity leads to diverging mental habits related to digital versus paper reading. These researchers posit that, nowadays, people have become habituated to a specific style of computer and tablet use. This style of use is inconsistent with extended reading and deeper comprehension of text. When we read from digital devices, we go into a kind of "autopilot" wherein our minds process the information we are reading in a particular way. Flanagan and Kaufman found that computer-reading tends to be more concrete and less attuned to nuance and abstract thinking. More recently, Singer and Alexander (2017) found that there were no differences between reading condition with relation to main idea comprehension questions, but students' comprehension of key facts supporting the main idea was superior when reading from paper. Interestingly, they also found that student *calibration* was off regarding which condition they would perform better in—in general, students tended to believe that they would perform better when reading digitally, when, in fact, they performed better on paper.

One important difference between the Singer and Alexander's study and Flanagan and Kaufman's study has to do with the length of text used. Singer and Alexander used a short text, whereas Flanagan and Kaufman used a longer text. This could account for Singer and Alexander's finding that the comprehension was better preserved in the digital condition, relative to the paper condition, than in Flanagan & Kaufman's study. Flanagan and Kaufman found a notable decline in performance on inference measures, but not on recall measures.

Meta-analysis of Studies Comparing Digital and Paper Reading Conditions

The wide range of findings discussed above suggests that a more systematic approach is necessary to uncover the differences in studies that may moderate the size and direction of the effect of digital presentation on reading comprehension. To do this, I conducted a meta-analysis of studies that compared reading comprehension outcomes from paper and digital reading presentations.

Search procedures and inclusion criteria for meta-analysis. On the PsycINFO database, several searches were performed using search terms intended to capture studies that included data on reading comprehension measures from computerized devices (e.g., "computer," "screen," "e-reader," "tablet," and "VDT and/or video display terminal"). Search terms that focused on the computerized aspects of studies were focused on (i.e., search terms for "paper" or "paper text" were not entered for fear that that might render results too limited). To capture studies that investigated reading comprehension, search terms such as "comprehension," "reading comprehension," and "reading" were used. Thirteen articles were found that fit criteria for inclusion in the analysis. A second search of the ERIC database using similar search terms did not yield any new articles. Additionally, footnotes of all included articles were searched for articles that could possibly fit inclusion criteria. Finally, a hand-search of the relevant journals was conducted to see if any suitable articles were missed. This included the *International Journal of Industrial Ergonomics,* and *Computers in Human Behavior*.

Inclusion in the meta-analysis was based on the following criteria. Studies must have the following characteristics:

1) a comparison between a paper condition and a digital screen reading condition;

2) measures of reading comprehension;

3) published means and standard deviations for the 2 groups (or other data from which an effect size could be obtained);

3) published in a peer-reviewed journal;

4) the subjects in the study had to be randomly assigned to the different conditions; and

6) the study had to occur after January 1, 1980.

Fifteen articles, containing a total of 33 different studies, were identified for inclusion in the meta-analysis based upon the above criteria. Studies included in the meta-analysis are marked with an asterisk in the references section.

Coding procedures for meta-analysis. As articles were examined, all relevant information was coded into an excel spreadsheet. The following categories were coded:

year published, text length, gender, age, type of screen (computer vs. tablet—electronic ink or LED), type of text (narrative or expository), learner type (LD, TL, ELL), type of comprehension measures (recall, semantic, and inferential), and whether the subjects took timed or untimed tests. Once all the information was coded, effect sizes were calculated using Cohen's *d*. In this method, means from test scores of digital readers were subtracted from scores of those who read paper texts, then the result was divided by their pooled standard deviation:

$(M_{digital} - M_{paper})/S_{pooled}$

Where: $S_{pooled} = \sqrt{[(n_{paper}-1)\, S^2{}_{Paper} + (n_{digital}-1)\, S^2{}_{digital})]/[(n_{paper} + n_{digital}) - 2]}$

M_{paper} = *Mean score for those who read paper texts*

$M_{digital}$ = *Mean score for those who read digital texts*

First, effect sizes were calculated by article. Then, each effect size was weighted by multiplying by the inverse of its standard error (Lipsey & Wilson, 2000). After effect sizes for each study were calculated, effect sizes were calculated by the different moderator variables described above.

Moderator variables were dummy-coded, with a "1" denoting the presence of a characteristic, and a "0" denoting absence of that characteristic. The following categories and subcategories were dummy-coded:

- Screen type: Computer, LED tablet, Digital ink tablet
- Time period: <2000, >2000 (i.e., before and after the year 2000)
- Measure type: Recall, Semantic, or Inference
- Passage type: narrative or expository

- Age: child (<12), teen (13-18), or adult (>18)
- Length of text: Long (>750 words) or Short (<750 words)
- Learner type: Learning Disabled, Typical Learners, or English Language Learners
- Time Limit: Timed, or Untimed

Screen type, measure type, passage type, length of text, and whether or not the study was timed all have direct implications for accurate comprehension. Each of these potential moderators has the potential to add to one's working memory load and thus harm reading comprehension. Both time period and age seem relevant for a related reason: both might serve as proxies for the familiarity that subjects may have with computer use. If there are differences in familiarity with digital devices, then it seems logical to think that those with more familiarity would have less working memory taken up with text navigation and device use. Alternatively, it could *also* be the case that those with more familiarity may be more distracted by habitual off-task behaviors that they frequently engage in on digital devices.

Learning-disabled students are known to have decreased working memory capacities (Siegel & Mazabel, 2013). Therefore, we would expect to see differences between typical learners and learning-disabled students in the degree to which each group is affected by reading modality. The same is true of English language learners—because they are simultaneously reading and comprehending as well as trying to decode a foreign language. As such their working memory is likely already overloaded—any added strain on working memory, such as digital text navigation, or technology-related distractors, would likely result in lower comprehension scores.

The “measure type” moderator variable was grouped into a “recall” group and a “comprehension” category that combined any measures that were more robust than recall—any semantic or inference type measures. This particular moderator was included in an attempt to possibly capture processing differences between the two conditions. Past studies have shown differences in the effect of digital reading on comprehension depending upon the level of understanding being measured (Gambrell, 1987; Kerr & Symons, 2006; Porion, et al., 2015; Kaufman & Flanagan, 2016).

Results from meta-analysis. The overall weighted effect of reading from a digital device was moderately negative, d = -.32 (Cohen, 1988). This means that, based upon the data included here, on average people performed .32 standard deviations worse on comprehension measures when they read from a digital screen.

Of the moderator variables that were included in the original coding procedures, only the categories of measure type, year published, and text length yielded enough effect sizes to be suitable for comparisons. Table 1 shows the effect sizes for the various moderators.

Table 1

Effect Sizes by Moderator

	Moderator					
	Long Text	Short Text	Recall	Comprehension	<2000	>2000
ES	-.33	-.07	.11	-.36	-.24	-.28
k	6	4	4	12	5	12
n	387	312	192	1074	225	1044

Note. ES=Effect Size; k=number of studies; n=sample size

Longer texts require a person to hold more information in working memory while reading—and again while answering questions. The effect size for long texts was -.33. Longer texts afford more opportunities for mistakes to be made in understanding the text, since more sustained attention is required to maintain an accurate understanding of the text. Consistent with this interpretation, there was no effect for subjects in the "short text" condition, regardless of the type of measure used. Studies that used comprehension measures yielded an overall weighted effect of -.36. Furthermore, when recall measures were used as the outcome, no significant effect was found—for either short or long texts. My findings here are consistent with Singer and Alexander's (2017) recent systematic review, in which they found that throughout the literature, there was a consistent interaction between text length and reading condition: those experiments that used longer texts tended to show that there was a decline in comprehension in the digital condition relative to paper. They found this result to be true in 91.67% of the studies they examined.

The work by Flanagan and Kaufman (2016) may hold the key to understanding these findings. It is possible that the increased negative effect that is seen in the more recent studies reflects an increased habituation to computer use, one that interferes with deeper comprehension (but not more concrete comprehension). The differences seen between effects on recall measures versus comprehension measures also suggests that this interpretation might be true.

The present study is informed by the fact that comprehension declines in the digital conditions of previous studies only seem to occur when longer texts are used. This, combined with the research on mind wandering and reading comprehension, led me to hypothesize that the comprehension declines found in studies like Flanagan and Kaufman's (2016) may have been mediated by increased mind wandering in the digital condition relative to the paper condition. Hollis and Was's (2016) finding that most mind wandering in a digital learning task was associated with thoughts about technology further led me to suspect that these comprehension declines were the result of increased mind wandering that was induced by the presence of the technology itself. My study is detailed in the following chapter.

CHAPTER III

METHODS

Participants

Participants were 169 9th and 10th graders at a Catholic high school near Palm Springs, CA.[1] Of the total sample in the present study, 91were female and 79 were male. The school population is 47% white (non-Hispanic), 26% Hispanic, 4% Asian/Pacific Islander, 2% African American, 1% Native American, and 20% two or more races. Nine percent of the student body is made up of international students. Forty-seven percent of students enrolled are on some form of need-based financial aid, and 38% of currently enrolled students will be the first generation in their family to attend college. The school has a 97% college attendance rate, and a 100% graduation rate. The school has a one-to-

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[1] The sample size is much larger than other similar studies in the research literature. Of a total of 15 articles included in the meta-analytic review discussed above, the average sample size was 84. The two most recent studies comparing reading comprehension outcomes on digital and paper text had sample sizes of 90 and 81 (Singer & Alexander, 2016; Flanagan & Kaufman, 2016; respectively), and both were able to detect significant effects of reading condition on a reading comprehension outcome.

The theoretical rationale for choosing 9th and 10th graders is based on the fact that this age group will yield a great degree of variance in executive control processes. The work of Stevens and Bavelier (2011) suggests that the development of executive control processes is still incomplete during adolescence, but is fully developed shortly thereafter. Therefore, in the 9th and 10th grade, when students are 15 to 16 years old, one would expect a great deal of variety in WMC. Because this study is utilizing the executive failure hypothesis of TUT, this variety in executive processing abilities should be closely related to a wide variety of time spent mind wandering. Using younger high school students also helps to flesh out the literature on digital reading, since most studies' subjects are college students. As more schools are implementing tablet programs, it is important that we understand learning processes on these devices within these younger populations.

one tablet program, such that students have a semester using tablets for academic purposes by the time they participate in the present study.

Prior to the study, the students' teacher asked their parents to sign a waiver to participate in the current study. Following IRB (#HS-18-042) procedure, students signed an assent form indicating that they volunteer for the study and that participation or non-participation had no effect on their grades. Students provided their reading sub-score from the most recent Preliminary Scholastic Assessment Test (PSAT). Students wrote their names on their test materials during testing occasions, but when data was entered for storage and analysis, names were deleted and replaced with ID numbers.

Students were randomly assigned to one of two conditions: Paper reading or digital reading. Due to potential class-related confounds, students were randomly assigned *within* classes. Teachers gave me class rosters before class, which were used to randomly assign students to either the digital or paper reading condition, using an online random number generator (odd = digital; even = paper). Nine different classes were used for the present study. Two classes were honors-level 10th-grade English classes, four classes were regular 10th-grade English classes, and three were 9th-grade "21st-century Skills" classes.

Materials

Mind Wandering Probe

Task-unrelated thought (TUT) was measured by using a mind wandering probe. The probe used in the current study was a modified version of the procedure used in a study by Hollis and Was (2016) to probe TUT during a video lecture task. Modifications were made to both the responses and to the procedures of administration to suit a group setting. The probe was administered in the same manner in both conditions (paper and digital). The probe was given on a projector screen on five occasions throughout the reading activity, at 1:00, 2:30, 3:30, 5:30, and 6:45. The timing of probes was determined by conducting a small pilot study to determine adequate timing. Pilot testing indicated that the earliest finishers finished no faster than 8 minutes, and the latest finishers took up to 15 minutes.

Participants had a response sheet with 5 identical responses that corresponded to each of the 5 probes. They were instructed to circle the appropriate response to the probe on their card each time a probe is presented. The probe asked participants, "In the last 5 seconds, what were you thinking about?" It contains eight possible responses:

a) *The reading*
b) *How well I'm understanding the reading*
c) *A memory from the past*
d) *Something in the future*
e) *My current state of being (for example: "I'm hungry or "I'm tired")*
f) *Using another technology or using my tablet in another way (for example, Facebook, texting, Twitter, Instagram, Snapchat, etc.)*
g) *Other*
h) *I have completed the reading*

Item 1 (a) indicated on-task behavior; item 2 (b) indicated task-related interference; items 3-7 (c to h) indicated TUT. Responses were coded as follows: 0 = no TUT; 1 = TUT. The resulting variable was continuous, with a minimum value of 0 and a maximum value of 5. This coding procedure is consistent with that used by Hollis and Was (2016), and the interpretation of each of the items is also consistent with previous uses of similar probes in the mind wandering literature (McVay & Kane, 2012; Unsworth & McMillan, 2012).[2]

For this study, probes were called “interruptions.” This was done to ensure there was no confusion, as *interruption* is a word that students would be more familiar with than *probe*. At the onset of each probe, I said, “Interruption 1,” “Interruption 2,” and so on, to indicate to the students that they should direct their attention to the screen and answer the corresponding answer on their response sheets.

Reading Materials

For the digital reading condition, participants used identical Acer Chromebooks provided by the school. Readings were presented in an online format which was accessed through a website. The URL was given to the students immediately prior to the start of the experiment. In the paper reading condition, participants were provided with

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[2]Each subject had a response sheet with five response sections—one for each probe. Participants were instructed to circle the appropriate letter to indicate their responses to each probe. The items in the current probe are identical to those used in the original study, except that video was replaced with reading to reflect the different learning task in the present study, and the eighth item was added due to the self-paced nature of reading—whereas Hollis & Was (2016) used video lectures of a set length. Having the probe displayed on a projector screen was a practical modification that ensures that the probe is the same for participants in both reading conditions.

paper copies of the readings. The reading was "A Hanging" by George Orwell (1931). It is 1,948 words long.

Reading Comprehension Measures

Inference-based comprehension test. This reading comprehension test required students to answer questions about the text that required *intratextual* inferences. The comprehension test was free response, and contained 4 questions, worth 2 points each. This experimental measure was highly correlated with student outcomes on the reading portion of the PSAT $r(169) = .62, p<.01$. Each item in the test was created such that a correct answer required information from more than one part of the text. For example, the second question in the test asked the following:

> *How does the dog's emotional state change over the course of the story? How do the events in the story affect the dog's behavior?*

It is never stated explicitly in the story whether the dog's behavior changes. However, a reader would know this by connecting several different parts of the text that describe the dog's behavior differently—and, in each case, the dog's behavior is thematically linked to other events in the story. Answering correctly required correct local and global inference-making. That is, students had to have correctly resolved inferences that utilized information from directly connected text, as well as inferences whose resolution required connecting information from different parts of the story (e.g., information from the last page and information from the first page). The reading comprehension test was graded on a scale from 1-8. Coding procedures are shown in Table 2 below.

Table 2

Reading Comprehension Test Grading Rubric.

Questions	**Grading Criteria**
1. Why does the narrator think that it's odd that the Hindu man steps aside to avoid a puddle? What is the significance of this moment in the story?	• *Student must mention that the Hindu man is on his way to be executed/that he's a prisoner. +1 point* • *Student must mention that this is the moment in the story when the narrator realizes that what he's doing is immoral. +1 point*
2. How does the dog's emotional state change over the course of the story? How do the events in the story affect the dog's behavior?	• *Student must explain that the dog is, at first, happy/playful/excited, then becomes sad/despondent/depressed. +1 Point* • *Student must connect the dog's behavioral change to the plot of the story—that his behavior changes from before the prisoner's death to afterward. +1 point*
3. The narrator describes a "sudden snap" after which there will be "one world less." a. What SOUND does the "sudden snap" refer to? b. What does the narrator mean when he writes that there will be "one world less"?	• *Student must identify the sound as either the rope tightening or the prisoner's neck snapping as he's hung. +1 point* • *Student must answer that this refers to the death of the prisoner. +1 point*
4. After the hangman pulls the lever, the narrator says that the prisoner "vanished." *Vanished*, as the narrator uses it here, has two meanings—can you identify them both?	*Vanishing refers to BOTH:* • *Dying. +1 point* • *Disappearing beneath the platform of the gallows. +1 point*

Recall test. The recall test was a cloze test that included two passages from the text with removed words from them. The first passage was 93 words long, and was taken from the first third of the reading. The second passage was 98 words long, and was taken from the last third of the reading. Each passage had six words removed. Where each word was removed, a numbered blank was put in its place. Below each passage, numbered multiple choice questions were provided. Students had to circle the correct word for each corresponding blank. Item options were created such that each option made grammatical sense—such that students could not "figure it out" easily based on grammar. The recall measure yielded a small correlation with the PSAT reading section, $r(108) = .28$, $p<.01$, and a moderate correlation with the experimental inference-based comprehension measure, $r(111) = .52$, $p<.01$. Correlations are shown in Table 8.

Listening Sentence Span

This task assesses students' abilities to remember a set of the last words from a series of spoken sentences, by holding them in working memory (WM) through rehearsal (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Swanson, 1992, 1995). At the same time, they have to understand and remember semantic information from each set of sentences, while also attempting to remember and recall the correct order of the last word from each sentence. Students listened as I read a series of sentences. Each sentence was followed by a short pause, so that students knew when one sentence ended and the next began. After each set, a "processing question" was asked that had to do with the meaning of one of the sentences. Students were instructed to write down the answer to the processing question, then try to recall the last words of each sentence, in order, and write them down.

Each set contained more sentences than the set before it. A total of 7 sets were given, beginning with a 1 sentence set, and moving up to an 8 sentence set. Students were scored by the number of correct words written in order, plus the correct process question. The process question of each set had to be answered correctly in order for the items in that set to be counted. All items in a set had to be correct in order for credit to be given for the subsequent set. For example, if a student got the process question correct in Set 2, but then did not recall all of the words in order, he/she would not be given credit for any subsequent correct answers. Incomplete answers were scored by adding up the process question, plus correct items in order. Incorrect insertions resulted in a deduction of one point.

Procedure

Nine classes participated in the study, during their normal class time. Each of the classes was tested on one occasion. Students who chose not to participate in the study were given another assignment by their teachers.

When students arrived for class, those in the digital condition were given Chromebooks. A URL was written on the board for students in the digital condition to access the reading. They were instructed to access the reading, but not to begin reading until I told them to do so. All students were then handed student assent forms and Interruption Response Sheets. Students in the paper condition were handed a paper copy of the reading.

Prior to the start of the experiment, I explained to the students that would be reading a short story by George Orwell, followed by a series of tests about the reading. Then, I explained the mind wandering probes, called “interruptions” in the actual testing situation. The “interruption” was displayed on an overhead projector, and I handed out interruption response sheets. I went over all of the response items on the response sheet, and students had a chance to ask clarifying questions if they did not understand any of the responses. Students were instructed that, for each interruption, I would say, “Interruption 1,” “Interruption 2,” “Interruption 3,” and so on, to indicate that they were to direct their attention to the projector screen. I simultaneously displayed the corresponding interruption on the screen. Students were instructed to circle the item on their response sheet that most closely corresponded to what they were thinking about in the previous 5 seconds. Students were instructed that if they felt that they were *both* on-task and off-task in the previous 5 seconds (if, for instance, they were off task, but had just recently redirected their attention, in the last second or two, back to the reading), they were to indicate the off-task behavior on their response sheets.

Once students had no more questions, I returned the interruption PowerPoint back to the blank, first slide, and instructed students to begin reading. Each interruption was administered by changing the PowerPoint to the next slide: *Interruption 1, Interruption 2,* and so on. The interruption slides were only shown for 10 seconds, then I moved the PowerPoint back to a blank slide in between each interruption.

Probes/interruptions were administered at 1:00, 2:30, 3:30, 5:30, and 6:45. Once the last probe was administered, students were given enough time to finish reading. At

10 minutes, or once it looked as if all students were finished, I asked if anyone needed more time. In each of the 9 occasions, there were a number of students who needed more time after the first time I asked. Also in each of the 9 occasions, all students were able to finish in less than 15 minutes.

Once all students had finished the reading, students were instructed to close their Chromebooks and put their names on all of their documents. They were also instructed to write whether they read from a Chromebook or from paper by writing *DIGITAL* or *PAPER* on the top of their interruption response sheet. I then collected all of the documents on students' desks: interruption response sheets, readings, and assent forms. Once all of these were collected and all students in the digital condition had closed their Chromebooks, I handed out the comprehension test, containing free-response items that were designed to tap inference-based text comprehension. Students were instructed to write in complete sentences. This task took students between 5 and 11 minutes to complete. Once all students were finished, I collected the comprehension tests, ensuring that they had written their full names on the tops of them. I then handed out the recall tests. Students were instructed that they were to try to remember the correct words from the reading that corresponded to each blank in the two passages.

Once all students completed the recall test, they were handed blank sheets of paper to write their answers to the listening span test. The listening span test was explained by providing an example, and writing the answers together on the whiteboard—eliciting student responses to answer the questions. I used the following script to explain the process:

I'm going to read some sentences to you and you will be asked to recall the last word in each sentence. Before you tell me the last word in each sentence, I will ask you a "process question." Write down the answer to my question, THEN, write down the last word in each sentence, in order. There will be a pause after the end of each sentence so that you know where one sentence ends and another begins. So, your job is to try to remember the last word in every sentence. DON'T write anything as I am reading. Pencils down until after the process question.
Here is an example: Many animals live on the farm. [Pause] Joey collects stamps. [Pause] Who lives on the farm? [Now, elicit student responses and write on the whiteboard]. A correct answer to this example would read: Animals, farm, stamps. Please let me know if you have any questions. This test involves 6 sets of increasing difficulty. Please go ahead and number your papers 1-6. You will write your responses in the manner that I did on the board, with each word listed left to right, separated by commas. Good luck! [Begin Listening Span test.]

Once the listening span test was over, I collected all of the students' papers, and thanked them for participating in the study.

CHAPTER IV

RESULTS

Descriptive Statistics

Tables 3-6 show the frequencies for all variables. A total of 170 students completed the study, but one student was later dropped from analysis because he was an exchange student with very limited English language ability, for a total of 169 students left in the analysis. Ninety were female (53.3%) and 79 were male (46.7%). Students were taken from nine different classes—3 9^{th}-grade classes and 6 10^{th} grade classes. Due to technical difficulties that some students had with their devices, the number of students in each reading condition ended up slightly uneven (89 in the paper condition, 80 in the digital condition).

Table 3

Gender

		Frequency	Percent	Valid Percent	Cumulative Percent
	Female	90	53.3	53.3	53.3
Gender	Male	79	46.7	46.7	100.0
	Total	169	100.0	100.0	

Table 4

Grade

		Frequency	Percent	Valid Percent	Cumulative Percent
	9	56	33.1	33.1	33.1
Grade	10	113	66.9	66.9	100.0
	Total	169	100.0	100.0	

Table 5

Class

		Frequency	Percent	Cumulative Percent
Class	1	22	13.0	13.0
	2	23	13.6	26.6
	3	20	11.8	38.5
	4	21	12.4	50.9
	5	15	8.9	59.8
	6	17	10.1	69.8
	7	18	10.7	80.5
	8	9	5.3	85.8
	9	24	14.2	100.0
	Total	169	100.0	

Table 6

Reading Medium

	Frequency	Percent	Valid Percent	Cumulative Percent
Paper	89	52.7	52.7	52.7
Digital	80	47.3	47.3	100.0
Total	169	100.0	100.0	

Table 7 below shows descriptive statistics for all variables. The maximum PSAT score is 800 points. Students in both 9th and 10th grades took the same version of the PSAT.

Listening Span

The ListSpan variable represents Listening Span scores that were scored on a continuous scale from 1 to a maximum score of 35. Due to the nature of the scoring procedure, many students did not advance beyond certain levels. Without advancing beyond a given level, no further points were awarded. Scoring procedures are further elaborated in Appendix F.

Task Unrelated Thought

TUT scores were coded as the sum of off-task behaviors captured for a given student, from probes 1 through 5. Due to the fact that this was a reading task, and time on task was variable from one student to another, a second method of coding was attempted wherein students' TUT scores were coded as a ratio of their time off task to their total time spent on the task. That is, if a student finished reading early, and they responded to the last probe that they had finished the reading (option *h*), then their TUT score would be a ratio of off-task behaviors over a denominator of 4, rather than 5 for most participants. However, when comparing the ratio-scale TUT scores to total sum scores, the results were identical—including correlations to other variables and relationships to the two outcome variables (inference comprehension and recall). For this reason, the TUT sum scores were retained. This also makes the results more easily interpreted (e.g., a TUT score of 3 means that a student was caught off-task on 3 occasions), and is consistent with how this and other similar instruments have been coded in previous research literature (Hollis & Was, 2016; McVay & Kane, 2012; Unsworth & McMillan, 2012).

Task Related Interference

TRI was *task related interference*, and corresponds to the second option on students' interruption response sheets used with the probe. This response was "I am thinking about how well I understand the reading." This response was grouped together with item response A (*The reading*) as on-task behavior. It is listed separately here because it is of interest whether students are reading or engaging in cognitive monitoring that attempts to gauge their understanding.

Inference-based Comprehension

The inference measure was scored from 0 to 8 points. Those students who scored a 0 were kept in the analysis because, while they may have been unable to answer inference-based comprehension questions, they were not hindered by either language-based learning issues (i.e., ELL) or learning disabilities. In fact, many of their answers indicated that they understood the reading—but they simply were not able to successfully make the inferences necessary to answer the questions on the inference comprehension test correctly. Consistent with (part of) my hypothesis, these students mind wandered more often than students with higher inference scores.

Recall

The recall measure was scored out of a total of 12 points. Questions were multiple-choice, and asked students to select the correct word that they recalled in a passage taken from the text. There was a moderate, positive correlation between recall scores and inference scores. That is, students who did not really understand the story could still have remembered surface-level details from the story, but were not likely to remember *as much* as students who understood the story better.

Table 7

Descriptive Statistics for Continuous Variables

	N		Mean	Median	SD	Min	Max
	Valid	Missing					
PSAT Reading	161	8	496.83	500.00	82.80	320	700
ListSpan	146	23	6.19	4.00	4.00	1	19
TUT	169	0	1.82	2.00	1.42	0	5
TRI	169	0	.91	1.00	.88	0	4
Inference	169	0	3.43	4.00	2.29	0	8
Recall	113	56	6.12	6.00	1.78	2	10

Note. PSAT=Preliminary Scholastic Assessment Test; ListSpan=Listening Span Test; TUT=Task Unrelated Thought; TRI = Task Related Interference; Inference=Inference-based Comprehension Test; Recall=Recall Test

Correlations

Table 8 shows the correlations among the observed variables. PSAT scores were significantly correlated to listening span, TUT, inference, and recall. This is consistent with the theoretical background discussed in chapter 2. Working memory capacity, captured in the listening span task, should be positively related to reading ability (which the PSAT-Reading measures). Further, it is not surprising that students with higher reading abilities mind wandered less often than students with lower abilities—part of the higher achievers' reading ability is likely related to superior executive control (which the listening span task also tapped). The inference measure was highly correlated to the PSAT score, $r(159)=.62$, $p < .01$, indicating that this experimental measure worked well in this sample. The moderate, positive correlation between PSAT reading scores and recall was expected. Recall tapped the degree to which students remembered surface-level information about the text (i.e., a word in a particular place).

The listening span test yielded a significantly positive relationship with the PSAT and significantly negative relationship with TUT. This pattern in the results is discussed in the *Limitations* section in Chapter V, below.

TUT had a moderate, positive relationship with the inference measure $r(167)=-.51$, $p<.01$). The results are consistent with the research literature discussed in Chapter II. This is an important finding. The mind wandering probes administered in the present study were modified from previous versions to be used in a group setting and to explore mind wandering on different reading mediums. This instrument and procedure may help future researchers who are interested in researching similar questions.

Table 8

Correlations of Continuous Variables

	PSAT	ListSpan	TUT	TRI	Inference	Recall
PSAT	1	.328**	-.474**	.160*	.616**	.281**
		p=.000	p=.000	p=.042	p=.000	p=.003
	N=161	N=138	N=161	N=161	N=161	N=110
ListSpan	.328**	1	-.168*	-.008	.206*	.146
	p=.000		p=.042	p=.926	p=.013	p=.169
	N=138	N=146	N=146	N=146	N=146	N=90
TUT	-.474**	-.168*	1	-.228**	-.510**	-.302**
	p=.000	p=.042		p=.003	p=.000	p=.001
	N=161	N=146	N=169	N=169	N=169	N=113
TRI	.160*	-.008	-.228**	1	.174*	-.035
	p=.042	p=.926	p=.003		p=.024	p=.716
	N=161	N=146	N=169	N=169	N=169	N=113
Inference	.616**	.206*	-.510**	.174*	1	.516**
	p=.000	p=.013	p=.000	p=.024		p=.000
	N=161	N=146	N=169	N=169	N=169	N=113
Recall	.281**	.146	-.302**	-.035	.516**	1
	p=.003	p=.169	p=.001	p=.716	p=.000	
	N=110	N=90	N=113	N=113	N=113	N=113

*$p < .05$; **$p < .01$

Note. *PSAT=Preliminary Scholastic Assessment Test; ListSpan=Listening Span Test; TUT=Task Unrelated Thought; TRI = Task Related Interference; Inference=Inference-based Comprehension Test; Recall=Recall Test*

Table 9

Point-Biserial Correlations of Reading Condition to Continuous Variables

	PSAT	ListSpan	TUT	TRI	Inference	Recall
Reading Condition	-.03	-.05	-.03	-.15*	.01	.14

**p < .05*

Note. PSAT=Preliminary Scholastic Assessment Test; ListSpan=Listening Span Test; TUT=Task Unrelated Thought; TRI = Task Related Interference; Inference=Inference-based Comprehension Test; Recall=Recall Test

Research Questions

Is the digital reading condition, when compared to paper reading condition, associated with declines in reading comprehension? If so, are these declines mediated by mind wandering?

No significant difference in reading comprehension between the digital and paper reading conditions emerged, $t(167) = .146$, $p = .88$. Because no significant treatment differences emerged, no mediation analysis was computed between the treatment condition and reading comprehension. It was assumed that declines in reading comprehension found in previous studies would be replicated, and that these declines would be mediated by TUT. Not only were previous results not replicated, but there was no relationship between reading condition and TUT, $t(167) = -.15$, $p = .88$.

Since the treatment conditions played no significant role in outcomes, I addressed the second part of the question that focused on whether declines in comprehension were related to mind wandering. A shown in Table 8, a significant correlation, $r(167) = -.51$, $p < .01$, emerged between TUT, as measured by the mind wandering probe, and inference-based comprehension (*inference*), suggesting that mind wandering was related to declines in reading comprehension. Furthermore, since the inference comprehension measure in this study was specifically designed to test students' abilities to successfully resolve intra-textual inferences, there was a slightly stronger relationship between TUT and the experimental comprehension measure than between TUT and students' PSAT Reading scores, $r(159) = -.47$, $p < .01$.

A regression analyses determined the percent of variance that TUT contributed to comprehension (*inference*) outcomes. As shown in Table 10, when controlling for reading ability (PSAT), TUT scores remained significant, explaining 7% more variance.

Table 10

Regression model with PSAT and TUT predicting inference-based comprehension

	Model	R^2	ΔR^2	*F*	*p*
Model 1	$Inference = B_0 + PSAT + \varepsilon$	.38	-	97.17	.000
Model 2	$Inference = B_0 + PSAT + TUT + \varepsilon$	.45	.07	65.82	.000

Note. Inference = Inference-based Comprehension; B_0=Interecept; PSAT=Preliminary Scholastic Assessment Test Reading sub-score; TUT=Task Unrelated Thought captured by mind wandering probe; ΔR^2=Change in variance explained from model 1 to model 2.

Is a significant amount of the TUT in the digital condition related to technology-related thoughts?

As previously indicated, there did not appear to be any systematic difference in amount or type of TUT as a function of reading condition. Frequencies of responses to each item as a percentage of the total off-task responses captured in each reading condition are shown in tables 11 and 12 below. Of primary interest, the technology response only accounted for 6% of TUT in the paper condition, and only 8% in the digital condition. However, these frequency differences were not significant, $\chi^2(1, N = 169) = .50, p = .48$.

Table 11

Frequencies of Off-Task Responses to Mind Wandering Probe – Paper Condition

	A memory from the past	*Something in the future*	*My current state of being*	*Using technology, or using my tablet in another way*	*Other*
%	*19%*	*21%*	*28%*	*6%*	*26%*

N=166

Table 12

Frequencies of Off-Task Responses to Mind Wandering Probe – Digital Condition

	A memory from the past	*Something in the future*	*My current state of being*	*Using technology, or using my tablet in another way*	*Other*
%	*22%*	*25%*	*23%*	*8%*	*23%*

N=158

CHAPTER V

DISCUSSION

The purpose of this study was to first replicate previous findings that showed a decline in reading comprehension when reading from a digital device compared to reading from paper. As in previous studies with these findings, the present study was conducted using a longer text and comprehension was measured using questions designed to tap deeper level comprehension requiring accurate inference-making. Upon replicating previous studies, I was then going to test whether this decline in comprehension in the digital reading condition was mediated by increased mind wandering in the digital condition, and then explore whether this increase was due to more technologically-related thoughts. No significant relationship was found between reading condition and reading comprehension, nor was a significant relationship between reading condition and mind wandering. Regardless of the treatment condition, the results did show that mind wandering, as captured by the mind wandering probes, was related to declines in reading comprehension on an inference-based comprehension measure. This finding was constant across both reading conditions. It did not matter whether students read from a tablet or from paper—text processing was the same regardless of reading condition. I discuss limitations and important implications of this study below.

Limitations

Group Setting

This study was conducted in a series of group settings. This may have had an effect on the precision of some of the measures used. The listening span task, for example, was adapted for use in the group setting—typically it is performed on an individual. In this task, it is important to check the students' understanding to make sure that he or she understands the "rules" of the task in order to accurately measure listening span. Even though I checked for understanding by eliciting student responses to the example and asking students if they had clarifying questions, it is possible that results were inaccurate for some students who did not completely understand the instructions. This could account for the number of students (n = 16) with scores of only 1, indicating that they were unable to move on to the first set with multiple sentences. Furthermore, the fact that this task requires sub-vocal rehearsal of phonological information makes it sensitive to auditory distraction. In the large group settings, there was more noise than in an individually administered, more highly controlled setting. Some students who may have otherwise performed better on this task, may have underperformed due to the distractions inherent in a group setting.

Time Limitations

I was able to conduct this study—and get a sample as large as I did—through the generous cooperation several teachers and administrators at my research site. In order to accommodate their schedules, I came in during class time that they gave up depending upon their class schedules. This meant that I had to come on different days and times for each of the teachers. As a result of the school schedule, on five of the nine occasions I did not have as much time as I had anticipated (due to an altered schedule that I was unaware of for 4 occasions, and due to an assembly going past its normal allotted time on another). This resulted in a loss of time to conduct some of the measures for this study—leading to some missing data.

The time limitations also led to decisions to leave out certain possible covariates, including motivation and interest. It would have been ideal to get measures on these two variables to see if, perhaps, these varied between reading condition. However, given the fact that random assignment appears to have worked regarding reading ability, and that no significant difference was found between groups on either of the outcome measures, nor on TUT, it seems as if random assignment likely took care of these two potential covariates.

Effect of Reading Condition on Comprehension

The result of "no effect" of reading condition on inference-based comprehension went against my expectations. It was believed that a negative effect would be found, given the importance of text-length as the most significant moderator of the effect of reading medium on comprehension, plus the fact that this effect was only seen in studies measuring comprehension (as opposed to recall). There could be several possible explanations for this. First, it could be due to the fact that so much of the research literature lacks precise coding and description of their measurement instruments—including text length and the nature of researcher-designed, experimental measures. It is possible that the results of my own meta-analysis were not as accurate as I believed, and perhaps there are other studies that used longer texts and found no effect on comprehension measures. The fact that so many previous studies *have* found a significant effect of reading medium on comprehension, however, remains significant.

Another possible explanation is that the age of the participants changed the outcome. Of the studies coded in my meta-analysis as both long and that included an outcome measure that was based upon deeper-level/inference-based comprehension measures, all but one were conducted using adult participants in their 20s (i.e., college students). It could be that within this small niche of studies where we see this effect—long readings with comprehension measures—the age of the participants plays some role in mediating the effect of the reading medium on text comprehension. However, within this group, there was one study that used students who were young high school students—just like my sample. Mangen, et al. (2013) had a sample of 72 15 and 16-year-olds. Their study found a negative effect of the reading condition on comprehension (d = -.43). In analyzing their study for differences, one potential difference arose. In the description, the authors state that the students used the computers daily. The relationships that the students in my study had with the devices was possibly somewhat different.

At the school where I conducted my research, they have a 1:1 tablet program that utilizes Acer Chromebooks. However, it is still in its infancy, having begun only nine months ago. Furthermore, while students are familiar with these devices, and all were able to log-in and use them in my reading task effortlessly, their use at school is *highly regulated.* The Chromebooks are kept in mobile carts that various teachers request as they need them, and teachers control the use of technology very tightly within their classrooms. In the majority of the classrooms that I used for this study, the teachers did not utilize these technologies very frequently. Six out of the nine classes were English classes, and they read all of their novels in paper form. In the remaining three classes, technology was frequently used. In those classes, their Chromebooks are locked in a cabinet in the classroom. They access the Chromebooks for class, but do not take them out of that class. All of these students were familiar with the Chromebooks, because they are used frequently at the school, in a variety of classroom settings. However, they do not use *the same* devices—i.e., students do not have “their own” school Chromebook. Rather, they all share devices that are kept under lock and key either in their classroom or in the information technology room (from which they are brought to specific classes upon request). My hypothesis was based on the idea that familiarity with the devices would trigger distracting thoughts about other kinds of technological activities that would need to be inhibited. It had not occurred to me that a) this might not apply to devices that were utilized in such a highly regulated manner only for specific academic purposes OR b) that student familiarity with technological devices, and the ways in which they typically use them, *would not transfer* across devices. That is, students may be habituated to use technology in particular ways (i.e., Facebook, Twitter, Snapchat, etc.), and these habits may distract students in the course of tasks that require sustained attention when they engage in such activities on their digital devices. However, it might be the case that these distractions, and the potential priming to mind wander that takes place when using their digital devices, is context-specific in a way that is *device*-specific. So, it could be the case that performance was not hindered because the students in my study have been “trained” to use their school-owned Chromebooks in very specific ways that have helped limit the degree to which they are distracted by thoughts of engaging in off-task behaviors on these devices—because they *very rarely, if ever* engage in off-task behaviors on these devices. This is in stark contrast to Hollis and Was's (2016) finding that 29% of off-task behaviors captured by their probe related to thoughts about technology—in their study, their subjects used their own devices (i.e., devices that they frequently used to engage in non-academic activities, like using Facebook, Twitter, Snapchat, etc.). This is an empirical question, and might be a fruitful area for future research in this area. It would be interesting to see if, in a future study, a "BYOD" (Bring Your Own Device) condition were added, whether there would be differences between the BYOD condition and a digital and paper condition like those in the present study.

The results here seem to suggest that the manner in which this school is rolling out its tablet program is highly successful. In this sense, these findings are important: they show a scenario in which a tablet program *has not* led to declines in student comprehension, and there were no processing differences uncovered by the mind wandering probes. It is important, however, that other researchers and educators not over-generalize these findings. They should not be interpreted as meaning that there are no processing differences between digital and paper reading. Taken within the context of the larger body of literature on this topic, my findings suggest that the cognitive processing of written text is context dependent. The unique context of the current study cannot be overstated: the teachers and administrators at this school should be praised for their conservatism and the caution with which they are approaching their tablet program.

Mind Wandering Probes

In addition to the main research question of this study—whether digital reading causes a decline in inference-based comprehension, and whether this is mediated by mind wandering—it was also of interest to see how well the mind wandering probes predicted inference-based comprehension, over and above pre-existing reading ability. The results of the regression, described in chapter IV, indicates that this measure worked well, thus showing that the modifications to previously used experimental thought-sampling probes can be adequately adapted for use in a group setting. This may help future researchers interested in studying mind wandering in classroom settings, during activities where it is not possible to individually administer a probe to each student on a computer screen.

Directions for Future Research

Even though this study has, on the surface, added to the "mixed" (and somewhat confusing) results in the literature of experiments that compare digital and paper reading, for a variety of reasons, these results answer some questions, and provide clues to guide future research. First of all, the results of the present study indicate that text length alone is probably not what is mediating the effect of digital reading on comprehension. If it were, then the findings of the present study would have conformed to those in the literature. There must, therefore, be some interaction going on that is not coded in previous studies. Future studies should compare *different types* of digital reading programs with paper reading. That is, the present study represents a highly regulated, in-school only tablet program. This could be compared with a "bring your own device" (BYOD) program, in which students use their own devices both in and out of school for both academic and non-academic purposes. A study that had both of these conditions, in addition to a paper condition, would be a better way to empirically test the hypothesis that differences in comprehension are mediated by mind wandering that is induced by distracting thoughts of habitual digital behaviors that are not task-related. If correct, a study designed in this way would find comprehension deficits only in the BYOD conditions—not in the in-school only tablet condition. This new hypothesis is suggested by the results of the present study, understood together with previous findings. Kaufman and Flanagan's (2016) study was conducted on familiar tablets, as was Mangen, et al.'s (2013). Furthermore, Hollis and Was (2016) found that a significant proportion of the mind wandering in their digital condition was about distracting thoughts that were related to other digital behaviors. Familiarity with devices seems to matter, but the familiarity in the present study was, perhaps, not the right "kind" to induce increased mind wandering.

Appendix A

“A Hanging” by George Orwell (1931)

It was in Burma, a sodden morning of the rains. A sickly light, like yellow tinfoil, was slanting over the high walls into the jail yard. We were waiting outside the condemned cells, a row of sheds fronted with double bars, like small animal cages. Each cell measured about ten feet by ten and was quite bare within except for a plank bed and a pot of drinking water. In some of them brown silent men were squatting at the inner bars, with their blankets draped round them. These were the condemned men, due to be hanged within the next week or two.

One prisoner had been brought out of his cell. He was a Hindu, a puny wisp of a man, with a shaven head and vague liquid eyes. He had a thick, sprouting moustache, absurdly too big for his body, rather like the moustache of a comic man on the films. Six tall Indian warders were guarding him and getting him ready for the gallows. Two of them stood by with rifles and fixed bayonets, while the others handcuffed him, passed a chain through his handcuffs and fixed it to their belts, and lashed his arms tight to his sides. They crowded very close about him, with their hands always on him in a careful, caressing grip, as though all the while feeling him to make sure he was there. It was like men handling a fish which is still alive and may jump back into the water. But he stood quite unresisting, yielding his arms limply to the ropes, as though he hardly noticed what was happening.

Eight o'clock struck and a bugle call, desolately thin in the wet air, floated from the distant barracks. The superintendent of the jail, who was standing apart from the rest of us, moodily prodding the gravel with his stick, raised his head at the sound. He was an army doctor, with a grey toothbrush moustache and a gruff voice. ‘For God's sake hurry up, Francis,’ he said irritably. ‘The man ought to have been dead by this time. Aren't you ready yet?’

Francis, the head jailer, a fat Dravidian in a white drill suit and gold spectacles, waved his black hand. ‘Yes sir, yes sir,’ he bubbled. ‘All iss satisfactorily prepared. The hangman iss waiting. We shall proceed.’

‘Well, quick march, then. The prisoners can't get their breakfast till this job's over.’

We set out for the gallows. Two warders marched on either side of the prisoner, with their rifles at the slope; two others marched close against him, gripping him by arm and shoulder, as though at once pushing and supporting him. The rest of us, magistrates and the like, followed behind. Suddenly, when we had gone ten yards, the procession stopped short without any order or warning. A dreadful thing had happened — a dog, come goodness knows whence, had appeared in the yard. It came bounding among us with a loud volley of barks, and leapt round us wagging its whole body, wild with glee at finding so many human beings together. It was a large woolly dog, half Airedale, half pariah. For a moment **it** pranced round us, and then, before anyone could stop it, it had made a dash for the prisoner, and jumping up tried to lick his face. Everyone stood aghast, too taken aback even to grab at the dog.

‘Who let that bloody brute in here?’ said the superintendent angrily. ‘Catch it, someone!’

A warder, detached from the escort, charged clumsily after the dog, but it danced and gambolled just out of his reach, taking everything as part of the game. A young Eurasian jailer picked up a handful of gravel and tried to stone the dog away, but it dodged the stones and came after us again. Its yaps echoed from the jail wails. The prisoner, in the grasp of the two warders, looked on incuriously, as though this was another formality of the hanging. It was several minutes before someone managed to catch the dog. Then we put my handkerchief through its collar and moved off once more, with the dog still straining and whimpering.

It was about forty yards to the gallows. I watched the bare brown back of the prisoner marching in front of me. He walked clumsily with his bound arms, but quite steadily, with that bobbing gait of the Indian who never straightens his knees. At each step his muscles slid neatly into place, the lock of hair on his scalp danced up and down, his feet printed themselves on the wet gravel. And once, in spite of the men who gripped him by each shoulder, he stepped slightly aside to avoid a puddle on the path.

It is curious, but till that moment I had never realized what it means to destroy a healthy, conscious man. When I saw the prisoner step aside to avoid the puddle, I saw the mystery, the unspeakable wrongness, of cutting a life short when it is in full tide. This man was not dying, he was alive just as we were alive. All the organs of his body were working — bowels digesting food, skin renewing itself, nails growing, tissues forming — all toiling away in solemn foolery. His nails would still be growing when he stood on the drop, when he was falling through the air with a tenth of a second to live. His eyes saw the yellow gravel and the grey walls, and his brain still remembered, foresaw, reasoned — reasoned even about puddles. He and we were a party of men walking together, seeing, hearing, feeling, understanding the same world; and in two minutes, with a sudden snap, one of us would be gone — one mind less, one world less.

The gallows stood in a small yard, separate from the main grounds of the prison, and overgrown with tall prickly weeds. It was a brick erection like three sides of a shed, with planking on top, and above that two beams and a crossbar with the rope dangling. The hangman, a grey-haired convict in the white uniform of the prison, was waiting beside his machine. He greeted us with a servile crouch as we entered. At a word from Francis the two warders, gripping the prisoner more closely than ever, half led, half pushed him to the gallows and helped him clumsily up the ladder. Then the hangman climbed up and fixed the rope round the prisoner's neck.

We stood waiting, five yards away. The warders had formed in a rough circle round the gallows. And then, when the noose was fixed, the prisoner began crying out on his god. It was a high, reiterated cry of ‘Ram! Ram! Ram! Ram!’, not urgent and fearful like a prayer or a cry for help, but steady, rhythmical, almost like the tolling of a bell. The dog answered the sound with a whine. The hangman, still standing on the gallows, produced a small cotton bag like a flour bag and drew it down over the prisoner's face. But the sound, muffled by the cloth, still persisted, over and over again: ‘Ram! Ram! Ram! Ram! Ram!’

The hangman climbed down and stood ready, holding the lever. Minutes seemed to pass. The steady, muffled crying from the prisoner went on and on, ‘Ram! Ram! Ram!’ never faltering for an instant. The superintendent, his head on his chest, was slowly poking the ground with his stick; perhaps he was counting the cries, allowing the prisoner a fixed number — fifty, perhaps, or a hundred. Everyone had changed colour. The Indians had gone grey like bad coffee, and one or two of the bayonets were wavering. We looked at the lashed, hooded man on the drop, and listened to his cries — each cry another second of life; the same thought was in all our minds: oh, kill him quickly, get it over, stop that abominable noise!

Suddenly the superintendent made up his mind. Throwing up his head he made a swift motion with his stick. ‘Chalo!’ he shouted almost fiercely.

There was a clanking noise, and then dead silence. The prisoner had vanished, and the rope was twisting on itself. I let go of the dog, and it galloped immediately to the back of the gallows; but when it got there it stopped short, barked, and then retreated into a corner of the yard, where it stood among the weeds, looking timorously out at us. We went round the gallows to inspect the prisoner's body. He was dangling with his toes pointed straight downwards, very slowly revolving, as dead as a stone.

The superintendent reached out with his stick and poked the bare body; it oscillated, slightly. ‘*He*'s all right,’ said the superintendent. He backed out from under the gallows, and blew out a deep breath. The moody look had gone out of his face quite suddenly. He glanced at his wrist-watch. ‘Eight minutes past eight. Well, that's all for this morning, thank God.’

The warders unfixed bayonets and marched away. The dog, sobered and conscious of having misbehaved itself, slipped after them. We walked out of the gallows yard, past the condemned cells with their waiting prisoners, into the big central yard of the prison. The convicts, under the command of warders armed with lathis, were already receiving their breakfast. They squatted in long rows, each man holding a tin pannikin, while two warders with buckets marched round ladling out rice; it seemed quite a homely, jolly scene, after the hanging. An enormous relief had come upon us now that the job was done. One felt an impulse to sing, to break into a run, to snigger. All at once everyone began chattering gaily.

The Eurasian boy walking beside me nodded towards the way we had come, with a knowing smile: ‘Do you know, sir, our friend (he meant the dead man), when he heard his appeal had been dismissed, he pissed on the floor of his cell. From fright. — Kindly take one of my cigarettes, sir. Do you not admire my new silver case, sir? From the boxwallah, two rupees eight annas. Classy European style.’

Several people laughed — at what, nobody seemed certain.

Francis was walking by the superintendent, talking garrulously. ‘Well, sir, all hass passed off with the utmost satisfactoriness. It wass all finished — flick! like that. It iss not always so — oah, no! I have known cases where the doctor wass obliged to go beneath the gallows and pull the prisoner's legs to ensure decease. Most disagreeable!’

‘Wriggling about, eh? That's bad,’ said the superintendent.

‘Ach, sir, it iss worse when they become refractory! One man, I recall, clung to the bars of hiss cage when we went to take him out. You will scarcely credit, sir, that it took six warders to dislodge him, three pulling at each leg. We reasoned with him. “My dear fellow,” we said, “think of all the pain and trouble you are causing to us!” But no, he would not listen! Ach, he wass very troublesome!’

I found that I was laughing quite loudly. Everyone was laughing. Even the superintendent grinned in a tolerant way. ‘You'd better all come out and have a drink,’ he said quite genially. ‘I've got a bottle of whisky in the car. We could do with it.’

We went through the big double gates of the prison, into the road. ‘Pulling at his legs!’ exclaimed a Burmese magistrate suddenly, and burst into a loud chuckling. We all began laughing again. At that moment Francis's anecdote seemed extraordinarily funny. We all had a drink together, native and European alike, quite amicably. The dead man was a hundred yards away.

1931

THE END

Appendix B

Inference-Based Comprehension Test

Reading Comprehension Test
Part I: Free Response

Please answer the following questions in complete sentences. Please address ALL PARTS of each question. Be as thorough as you possibly can!

1. Why does the narrator think that it's odd that the Hindu man steps aside to avoid a puddle? What is the significance of this moment in the story?

2. How does the dog's emotional state change over the course of the story? How do the events in the story affect the dog's behavior?

3. The narrator describes a "sudden snap" after which there will be "one world less."
    a. What SOUND does the "sudden snap" refer to?

    b. What does the narrator mean when he writes that there will be "one world less"?

4. After the hangman pulls the lever, the narrator says that the prisoner “vanished.” *Vanished,* as the narrator uses it here, has two meanings—can you identify them both?

Appendix C

Recall Test

Part II: Fill-in-the-blank

The following passages have been reproduced from the reading, with some of the words missing. Please circle the correct response for each corresponding blank.

It is curious but till that moment I had never realized what it means to (1)________________ a healthy, conscious man. When I saw the (2)________________ step aside to avoid the puddle, I saw the mystery, the unspeakable wrongness, of (3) ________________ a life short when it is in full tide. This man was not (4)________________, he was alive just as we were alive. All the organs of his body were working — bowels digesting (5)________________, skin renewing itself, nails (6)________________, tissues forming — all toiling away in solemn foolery.

1.
    a. kill
    b. obliterate
    c. terminate
    d. destroy
2.
    a. man
    b. inmate
    c. prisoner
    d. person
3.
    a. ending
    b. cutting
    c. making
    d. finishing
4.
    a. dead
    b. sick
    c. incapacitated
    d. dying
5.
    a. nutrients
    b. food
    c. meals
    d. sustenance
6.

a. long
b. sharp
c. growing
d. dirty

……

There was a clanking noise, and then (7)____________ silence. The prisoner had (8)____________, and the rope was twisting on itself. I let go of the dog, and it galloped immediately to the back of the (9)____________; but when it got there it stopped short, barked, and then (10)____________ into a corner of the yard, where it stood among the (11)____________, looking timorously out at us. We went round the gallows to inspect the prisoner's body. He was (12)____________ with his toes pointed straight downwards, very slowly revolving, as dead as a stone.

7.
a. a long
b. deafening
c. dead
d. awkward

8.
a. disappeared
b. vanished
c. escaped
d. died

9.
a. gallows
b. machine
c. stage
d. cell

10.
a. recoiled
b. cowered
c. withdrew
d. retreated

11.
a. tall grass
b. trees
c. weeds
d. shrubbery

12.

a. dangling
b. hanging
c. swinging
d. swaying

Appendix D

Mind Wandering Probes

Interruption 1

In the last 5 seconds, what were you thinking about?

Interruption 2

In the last 5 seconds, what were you thinking about?

Interruption 3

In the last 5 seconds, what were you thinking about?

Interruption 4

In the last 5 seconds, what were you thinking about?

Interruption 5

In the last 5 seconds, what were you thinking about?

Appendix E

Mind Wandering Probe Response Sheet

Please circle the appropriate response for each interruption.

<u>Interruption 1</u>

a) **The reading**
b) **How well I'm understanding the reading**
c) **A memory from the past**
d) **Something in the future**
e) **My current state of being (for example: "I'm hungry" or "I'm tired")**
f) **Using technology, or using my tablet in another way (for example, Facebook, Twitter, Instagram, Snapchat, or checking email, texts, etc.)**
g) **Other:**
h) **I have completed the reading**

<u>Interruption 2</u>

a) **The reading**
b) **How well I'm understanding the reading**
c) **A memory from the past**
d) **Something in the future**
e) **My current state of being (for example: "I'm hungry" or "I'm tired")**
f) **Using technology, or using my tablet in another way (for example, Facebook, Twitter, Instagram, Snapchat, or checking email, texts, etc.)**
g) **Other:**
h) **I have completed the reading**

<u>Interruption 3</u>

a) **The reading**
b) **How well I'm understanding the reading**
c) **A memory from the past**
d) **Something in the future**
e) **My current state of being (for example: "I'm hungry" or "I'm tired")**

f) **Using technology, or using my tablet in another way (for example, Facebook, Twitter, Instagram, Snapchat, or checking email, texts, etc.)**
g) **Other:**
h) **I have completed the reading**

<u>Interruption 4</u>

a) **The reading**
b) **How well I'm understanding the reading**
c) **A memory from the past**
d) **Something in the future**
e) **My current state of being (for example: "I'm hungry" or "I'm tired")**
f) **Using technology, or using my tablet in another way (for example, Facebook, Twitter, Instagram, Snapchat, or checking email, texts, etc.)**
g) **Other:**
h) **I have completed the reading**

<u>Interruption 5</u>

a) **The reading**
b) **How well I'm understanding the reading**
c) **A memory from the past**
d) **Something in the future**
e) **My current state of being (for example: "I'm hungry" or "I'm tired")**
f) **Using technology, or using my tablet in another way (for example, Facebook, Twitter, Instagram, Snapchat, or checking email, texts, etc.)**
g) **Other:**
h) **I have completed the reading**

Appendix F

Listening Span Test

Examiner says: ***I'm going to read some sentences to you and you will be asked to recall the last word in each sentence. Before you tell me the last word in each sentence, I will ask you a "process question." Write down the answer to my question, THEN, write down the last word in each sentence, in order. There will be a pause after the end of each sentence so that you know where one sentence ends and another begins.***
Here is an example: Many animals live on the farm. [Pause] Joey collects stamps. [Pause] Who lives on the farm?
A correct answer to this example would read: Animals, farm, stamps. Please let me know if you have any questions. [Write on the whiteboard]
I have handed you each a blank sheet of paper, please use this to mark your responses. On the top of the paper, please write your full name. Before each set of sentences, I will ask you to number the set.

Set 1:
Sarah wants you to give her a dollar. [pause]
Mary tried to tell her teacher the right street. [pause]
Who did Mary try to tell?

Set 2:
The captain does not seem to have friends. [pause]
Beth can't go because she didn't get shoes. [pause]
Bob doesn't want to tell the teacher. [pause]
Who can't go?

Set 3:
My little brother went in the wrong restaurant. [pause]
The teacher wanted to see me about my book. [pause]
You will be sorry if you break the window. [pause]
My friend wants to learn about snakes. [pause]
Who will be sorry?

Set 4:
I can study if you give me a pencil. [pause]
Children like to read books about animals. [pause]
I will give Cathy the sweets in a bowl. [pause]
The good news gave Ann a feeling of happiness. [pause]
Jeff likes to do homework in ink. [pause]
What will I give to Cathy?

Set 5:

The broken doll was not my fault. [pause]
Joe is having problems with his memory. [pause]
I have talked to my parents about the idea. [pause]
John is not in a very good mood. [pause]
They were all happy to be at the event. [pause]
It is important to think about safety. [pause]
What was broken?

Set 6:
If you work hard you can make a discovery. [pause]
We didn't buy the car because of the cost. [pause]
I would like to know your opinion. [pause]
If you work hard you can make a table. [pause]
I would like to know your grandmother. [pause]
The good news gave Cindy a feeling of hope. [pause]
They were all happy to be at the cabin. [pause]
I will give Sam candy in a moment. [pause]
What was given to Cindy?

Scoring: In each set, the process question must be answered correctly in order for that set to count. For each set with a correct answer to the process question, the score is the total number of correct words IN THE CORRECT ORDER, plus the answer to the process question. Insertions of incorrect words between correctly ordered words result in -1 point. If there are more than two insertions between correctly ordered words, then they are not considered in the right order, and no further points are awarded. The total raw score is the score for each set added together, ending with the final set with a correct process question, plus correct words in order in that set.

Appendix G

Parental Consent Form

Parental Consent to Participate in a Research Study Version 2: 04/05/2018 Purpose of this research study

The purpose of this experimental research study is to investigate whether reading from tablet computers causes declines in reading comprehension. This research study will also investigate whether there is a connection between reading from tablets and an increase in mind wandering. Your child will be randomly assigned to either a paper or digital reading condition. This will allow researchers to determine whether the reading condition (digital or paper) was responsible for differences in reading comprehension. Approximately 140 students will participate in this research study.

The research study will be conducted by Brooks Imel, a doctoral candidate in educational psychology at the University of California, Riverside, under the guidance of his advisor, Dr. Lee Swanson.

Procedures

By signing this assent form, you grant the researcher permission to access your child's reading sub-score from the PSAT. The researcher will provide your child's signed assent form, and the parental consent form, to the Xavier College Guidance Office. The Director of College Guidance, Peter Kulevich, will then provide the researcher with your PSAT reading subscore. This score will be used to help make sure that the measures used by the researchers are consistent with your child's underlying reading comprehension abilities. This will also help the researchers make sure that the students in the two groups (digital and paper) have similar average reading comprehension abilities.

At the beginning of the research study, your child will take a short test that will measure his or her working memory capacity. This test should only take approximately 5 minutes to complete. He or she will then be asked to read a short story. While they are reading the short story, the researcher will occasionally interrupt them and have them answer a short questionnaire about their thoughts in the current moment. When they are finished reading, they will take a very short reading comprehension test.

Participating in this research study will take no longer than 45 minutes.

Participation or non-participation in this research study has no bearing on your child's academic standing. Furthermore, school administrators will not be able to identify individuals by their results in this research study, and results cannot be used to determine academic standing.

Risks

There are no risks associated with participation in this research study. Your child will not be asked to do anything that would not be considered normal in a school setting.

Benefits

There are no direct benefits associated with participating in this research study. By participating, your child is helping to improve our understanding of how the human mind interacts with tablet computers while reading. This will be a valuable contribution to scientific knowledge of human- computer interaction.

Confidentiality

The researcher will protect confidential information by removing your name from his records and replacing it with a "subject number" once all data is collected. Data will be stored on a password-protected hard-drive.

Other than the researcher, it is also possible that a representative from the University of California, Riverside Office of Research Integrity (ORI) may review research-related records for quality assurance purposes. This representative would do so only to ensure that relevant laws and guidelines are followed by the researcher. All information accessed by the ORI will be held to the same level of confidentiality that has been stated by the researcher.

Right to Withdraw

Your child may withdraw from this research study AT ANY TIME. Signing this form does not constitute any kind of commitment on your child's part. If your child wishes to withdraw from the research study, please notify the researcher, Brooks Imel.

Contact Information

Researcher: Brooks Imel
Email: rimel001@ucr.edu

If you have questions about your rights or complaints as a research subject, please contact the IRB Chairperson at (951) 827 - 4802 during business hours, or to contact them by email at irb@ucr.edu.

Voluntary Participation

Participating in this research study is completely voluntary. Your child has the right to withdraw from the research study at any time. Neither reimbursement or compensation will be offered for participation in this research study.

Signature

Parent/Guardian: By signing below, you give permission for your son/daughter to participate in the above-described study. This includes permission for the researcher, Brooks Imel, to access your child's PSAT scores through the Xavier College Guidance Office.

Full Name (Print)___________________________________
Signature _______________________________________
Date_________________________

Appendix H

Student Assent Form

Assent to Participate in a Research Study **Version 2: 04/05/2018 Purpose of this research study**

The purpose of this experimental research study is to investigate whether reading from tablet computers causes declines in reading comprehension. This research study will also investigate whether there is a connection between reading from tablets and an increase in mind wandering. You will be randomly assigned to either a paper or digital reading condition. This will allow researchers to determine whether the reading condition (digital or paper) was responsible for differences in reading comprehension. Approximately 140 students will participate in this study.

The research study will be conducted by Brooks Imel, a doctoral candidate in educational psychology at the University of California, Riverside, under the guidance of his advisor, Dr. Lee Swanson.

Procedures

By signing this assent form, you grant the researcher permission to access your reading sub-score from the PSAT. The researcher will provide your signed assent form, and your parental consent form, to the Xavier College Guidance Office. The Director of College Guidance, Peter Kulevich, will then provide the researcher with your PSAT reading sub-score. This score will be used to help make sure that the measures used by the researchers are consistent with your underlying reading comprehension abilities. This will also help the researchers make sure that the students

in the two groups (digital and paper) have similar average reading comprehension abilities.

At the beginning of the research study, you will take a short test that will measure your working memory capacity. This test should only take approximately 5 minutes to complete. You will then be asked to read a short story. While you are reading the short story, the researcher will occasionally interrupt you and have you answer a short questionnaire about your thoughts in the current moment. When you are finished reading, you will take a very short reading comprehension test.

Participating in this research study will take no longer than 45 minutes.

Participation or non-participation in this research study has no bearing on your academic standing. Furthermore, school administrators will not be able to identify individuals by their results in this research study, and results cannot be used to determine academic standing.

Risks

There are no risks associated with participation in this research study. You will not be asked to do anything that would not be considered normal in a school setting.

Benefits

There are no direct benefits associated with participating in this research study. By participating, you are helping to improve our understanding of how the human mind interacts with tablet

computers while reading. This will be a valuable contribution to scientific knowledge of human- computer interaction.

Confidentiality

The researcher will protect confidential information by removing your name from his records and replacing it with a "subject number" once all data is collected. Data will be stored on a password-protected hard-drive.

Other than the researcher, it is also possible that a representative from the University of California, Riverside Office of Research Integrity (ORI) may review research-related records for quality assurance purposes. This representative would do so only to ensure that relevant laws and guidelines are followed by the researcher. All information accessed by the ORI will be held to the same level of confidentiality that has been stated by the researcher.

Right to Withdraw

You may withdraw from this research study AT ANY TIME. Signing this form does not constitute any kind of commitment on your part. If you wish to withdraw from the research study, please notify the researcher, Brooks Imel.

Contact Information

Researcher: Brooks Imel
Email: rimel001@ucr.edu

If you have questions about your rights or complaints as a research subject, please contact the IRB Chairperson at (951) 827 - 4802 during business hours, or to contact them by email at irb@ucr.edu.

Voluntary Participation

Participating in this research study is completely voluntary. You have the right to withdraw from the research study at any time. Neither reimbursement or compensation will be offered for participation in this research study.

Signature

By signing below, you are granting your voluntary assent to participate in the above-described research study. This includes permission for the researcher, Brooks Imel, to access your PSAT scores through the Xavier College Guidance Office.

Please be aware that signing this assent form is not sufficient to participate in this research study. You must ALSO have a parent/guardian sign the parental consent form and return to the researcher.

Full Name (Print)___________________________________
Signature ______________________________________
Date_________________________

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