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Cognitive map or medium materiality? Reading on paper and screen

Jinghui Hou [a, *], Justin Rashid [b], Kwan Min Lee [c]

[a] School of Communication, Florida State University, C3115 University Center, Tallahassee, FL, 32306, United States
[b] Annenberg School for Communication and Journalism, University of Southern California, 3502 Watt Way, Los Angeles, CA, 90089, United States
[c] Department of Interaction Science, Sungkyunkwan University, Sungkyunkwan-Ro, Jongno-Gu, Seoul, 110-745, South Korea

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ABSTRACT

The present study examined two common mechanisms that are used to explain why reading on an electronic screen versus paper result in different reading outcomes: The Cognitive Map Mechanism and the Medium Materiality Mechanism. A laboratory experiment (N = 45), was conducted using a three-group comparison design (paper book vs. digital equivalent vs. digital disrupted view). Our hypotheses that were based on the cognitive map mechanism were largely supported. On the other hand, our hypotheses following the medium materiality mechanism were not sufficiently evidenced. Specifically, our results showed that the paper book was similar to its digital equivalent, and both were better than the digital disrupted view in terms of reading comprehension, feelings of fatigue, and psychological immersion. The findings implied that it is not the materiality of the presentation medium that influences reading outcomes, rather it is the extent to which the text presentation facilitates, or impedes, the reader's ability to construct a cognitive map that influences the reading process. Implications for future research and practice are discussed.

1. Introduction

Since the 1980s, scholars in many fields – including psychology, media studies, computer engineering, and information science and library – have published extensive studies investigating one question: How does reading on screens differ from reading papers? To date, this fundamental research question remains partially addressed at best. By the early 1990s, most studies concluded that people read slower, less accurately, and less comprehensively on screens than from papers (e.g., Gould & Grischkowsky, 1984; Muter, Latremouille, Treurniet, & Beam, 1982; Smedshammar, Frenckner, Nordquist, & Romberger, 1989; Wright & Lickorish, 1983). Research published since then, on the contrary, has produced mixed results. Some studies have confirmed previous conclusions (Kim & Kim, 2013; Kurniawan & Zaphiris, 2001), while many more have found few significant differences in reading speed, accuracy of recall, or comprehension between paper and screen (Margolin, Driscoll, Toland, & Kegler, 2013; Kretzschmar et al., 2013; Noyes & Garland, 2003).

Attempts to explain the reasons *why* reading on a screen versus paper might result in different reading outcomes center on two mechanisms. The first mechanism is concerned with the psychological aspects of reading behavior. It contends that screens make it difficult for readers to construct an effective *cognitive map*, or a spatial representation, of the text (Li, Chen, & Yang, 2013; Payne & Reader, 2006). This weak efficiency for constructing cognitive maps, in turn, impairs navigational performance (i.e., searching for or locating a piece of textual information), reading speed, content recall, and reading comprehension (Li et al., 2013; Payne & Reader, 2006). The second mechanism focuses on the material characteristics of the presentation medium (screen or paper), and it suggests that the materiality of the reading medium influences text processing (Mangen & Schilhab, 2012; Mangen, 2008). Text on paper is touchable and tangible, whereas text on screens is intangible, mediated, and detached from the physical support of the reading medium. The haptic interactions with paper text afford readers richer sensorimotor engagement with the text compared to screen text, which enhances information encoding and comprehension.

Research comparing reading on paper versus screens has still shown inconsistent findings, partly because the majority of the studies have not employed a rigorously controlled design to isolate the effects of the two mechanisms. Due to the lack of controlled designs, one mechanism appeared to be a confounding factor for the other. The main goal of the present study is to disentangle the

* Corresponding author.
E-mail addresses: jhou@fsu.edu (J. Hou), jrashid@usc.edu (J. Rashid), kwanminlee@gmail.com (K.M. Lee).

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effects of the two mechanisms. Utilizing a uniquely designed experiment stimulus, this study is among the first to compare and test the two mechanisms in the area.

2. Literature review

2.1. The cognitive map mechanism

Researchers believed that human minds automatically treat written texts as if they were physical objects (Jabr, 2013; Wolf, 2007). Evolutionary psychologists proposed that the human brain is an evolved organ with a range of functionally distinct mechanisms, or "modules," designed to guide specific adaptive behaviors, such as hunting for food, escaping danger, and selecting a mate (Chomsky, 1980; Sherry & Schacter, 1987; Cosmides & Tooby, 1992, 1994). The behavior of reading is a relatively recent human invention in evolutionary history. There is no direct module specifically dedicated to this new skill (Wolf, 2007). Instead, reading relies on an array of existing modules, such as vision, speech, motor coordination, and visual object recognition (Jabr, 2013; Nakamura et al., 2012). Visual object recognition is the ability to rapidly detect and classify objects despite the substantial variation in appearance that each object produces on our eyes (DiCarlo, Zoccolan, & Rust, 2012). Our ability to distinguish an apple from an orange or to recognize the words on this page depends on this objective recognition module (DiCarlo et al., 2012). Recent fMRI studies have also provided evidence that the brain circuit specialized for visual object recognition is activated during reading (e.g., Nakamura et al., 2012).

Furthermore, human brains not only treat a text as a tangible part of the physical world, but also perceive a text within its structure as a physical landscape. When the human brain gathers visual information about an object, it also gathers information about its surroundings, and associates the two (Jabr, 2013; Li et al., 2013). In a similar manner to how people construct a mental map of a physical environment (e.g., a desk in the center of an office facing the door), readers form a "cognitive map" of the physical location of a text and its spatial relationship to the page as a whole (Jabr, 2013; Li et al., 2013; Payne & Reader, 2006; Waller, 1985). For example, both scholarly evidence and anecdotal experience testify that when people try to locate a particular piece of information they have read, they often are able to recall where in the text it appeared, such as a limerick on the top of a right-hand page (Rothkopf, 1971). Thus, during the reading process, people acquire knowledge of a document's structure, as well as the contents of the document (Payne & Reader, 2006).

It is generally agreed that paper books make it easier for readers to form a coherent cognitive map of the text than onscreen texts (Jabr, 2013). Paper books have fixed layouts. A single page of a paper book presents a reader with four corners and a frame – two long and two short borders – with which to orient oneself. A reader can see where a piece of textual information is in relation to the page corners and borders. One can also sense the relative spatial relationship between texts within a page (Hansen & Haas, 1988; Morineau, Blanche, Tobin, & Guéguen, 2005; Li et al., 2013). The fixed layout of a paper book provides a reader with cues to the structure of a text, thus facilitating the construction of cognitive maps of the text. In other words, the fixed layout conveys structure information that a reader is able to use in forming a cognitive map of the document. With a coherent mental map in mind, a reader has better knowledge of a text's structure, and is more unconsciously aware of one's place in the document (Crestani & Ntioudis, 2001). Such spatial knowledge helps a reader to locate text one has seen before (Liesaputra & Witten, 2012), and support more effective retention and comprehension of the content (Chun & Jiang, 1998; Li et al., 2013; Morineau et al., 2005).

In contrast to paper books, screens, in general, weaken the spatial cues about a reader's location in a text (Dillon, 1992; O'Hara & Sellen, 1997; Liesaputra & Witten, 2012; McDonald & Stevenson, 1998), and they impede the reader in forming an effective cognitive map (Jabr, 2013; Li et al., 2013). When the cognitive map is not effectively constructed, a reader employs greater cognitive resources to navigate texts and to retain information, which leaves the reader less cognitive capacity for information recall and comprehension (Li et al., 2013). For example, empirical studies on hypertext reading have provided evidence for the cognitive map mechanism. Hypertext is a type of electronic text that connects ("hyperlinks") to other texts. Hypertexts have been shown to impede users in forming cognitive maps of the complexly structured texts, create disorientation (Payne & Reader, 2006; Simpson & McKnight, 1990) and cognitive overload in readers (Conklin, 1987; Stanton, Correia, & Dias, 2000), and impair reading comprehension performance (DeStefano & LeFevre, 2007). Scholars have contended that the "disorientation" problem associated with reading hypertext is a consequence of readers failing to construct an effective cognitive map of the flexibly structured hypertexts (Elm & Woods, 1985; Leventhal, Teasley, Instone, Rohlman, & Farhat, 1993; Payne & Reader, 2006; Simpson & McKnight, 1990). Such a disorientation problem can be alleviated by providing hypertext readers an explicit visual structure map, which aids readers in cognitive map formation (e.g., Li et al., 2013).

In summary, the cognitive map mechanism argues that the extent to which a text presentation facilitates or attenuates the construction of a cognitive map of its structure is the key factor that influences navigational performance (Li et al., 2013; Simpson & McKnight, 1990), content retention (Chun & Jiang, 1998; Morineau et al., 2005), and comprehension (Li et al., 2013; Morineau et al., 2005). A text presentation supporting the formation of a mental map of the text structure, such as a text on a paper, bolsters recall and comprehension performance, while a text presentation with weak efficacy for forming a mental map, such as text on a screen, impairs such performance.

2.2. The medium materiality mechanism

Another primary mechanism to explain the potential differences between reading on paper versus on a screen is concerned with the material characteristics of the presentation medium. Initially, scholars (Belmore, 1985; Bevan, 1981; Gould & Grischkowsky, 1986; Gould et al., 1987; Gray, 1991; Noyes & Garland, 2003; Ziefle, 1998) explained the differences in reading speed and comprehension in the context of the physical novelties and constraints inherent in the use of a screen (e.g., screen contrast, optical strain, backlighting and flickering, display quality, and page manipulation). Reading on a screen involves both processing the reading text and handling the reading medium. Thus, a screen might impose additional cognitive load to control the reading medium, leaving less cognitive capacity to deal with the text itself (Wastlund, Reinikka, Norlander, & Archer, 2005; Mayes, Sims, & Koonce, 2001). In contrast, a paper book is a physically and functionally unitary object. The interaction with paper books is so natural, intuitive, and immediate that readers cease to cognitively process it; therefore, it has lower cognitive demands.

However, it should be noted that such discrepancies were observed primarily by early work that compared paper text to text on the first generation of video display terminals (VDTs) (Dillon, McKnight, & Richardson, 1988). It is possible that some of these discrepancies have reduced due to the remarkable advances in screen technology (Margolin et al., 2013). For instance, previous studies reported increased visual fatigue and eyestrain when