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Understanding metacognitive inferiority on screen by exposing cues for depth of processing

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Paper-and-pencil learning and testing are gradually shifting to computerized environments. Cognitive and metacognitive researchers find screen inferiority compared to paper in effort regulation, test performance, and extent of overconfidence, in some cases, with unknown differentiating factors. Notably, these studies used reading comprehension tasks involving lengthy texts, which confound technology-related and cognitive factors. We hypothesized that the medium provides a contextual cue which leads to shallower processing on screen regardless of text length, particularly when task characteristics hint that shallow processing is legitimate. To test this hypothesis, we used briefly phrased yet challenging problems for solving on screen or on paper. In Experiment 1, the time frame for solving the problems was manipulated. As with lengthy texts, only time pressure resulted in screen inferiority. In Experiment 2, under a loose time frame, the same problems were now framed as a preliminary task performed before a main problem-solving task. Only the initial task, with reduced perceived importance, revealed screen inferiority similarly to time pressure. In Experiment 3, we replicated Experiment 1's time frame manipulation, using a problem-solving task which involved reading only three isolated words. Screen inferiority in overconfidence was found again only under time pressure. The results suggest that metacognitive processes are sensitive to contextual cues that hint at the expected depth of processing, regardless of the reading burden involved.

1. Introduction

Over recent decades, paper-and-pencil work has been shifting to computerized environments for many types of cognitive tasks in everyday contexts, including learning (e.g., MOOCs), work-related and academic screening (e.g., the GMAT and SAT), and surveys, as well as scientific research. This shift has been driven mainly by practical considerations, such as lower costs, automatic grading, and easy access to a wide audience, although, of course, computerized environments also allow novel task designs (e.g., Buhrmester, Kwang, & Gosling, 2011; Csapó, Ainley, Bennett, Latour, & Law, 2012; Dennis, Abaci, Morrone, Plaskoff, & McNamara, 2016; Mason & Suri, 2012; Quellmalz & Pellegrino, 2009).

While there is no doubt about the important advantages of computerized environments, the technological revolution compels us to ask what effects the medium might have on cognitive performance. Research in this area has yielded inconclusive results. On the one hand, there is evidence for both a subjective preference for paper (e.g., Holzinger et al., 2011; Kazanci, 2015; Mizrachi, 2015; Singer & Alexander, 2017; Woody, Daniel, & Baker, 2010; van Horne, Russell, & Schuh, 2016) and actual better performance on paper, relative to working on screen (e.g., Ben-Yehudah & Eshet-Alkalai, 2014; Daniel & Woody, 2013; Lin, Wang, & Kang, 2015; Mangen, Walgermo, & Brønnick, 2013). On the other hand, some studies have found no performance differences between the two environments, and several even point to screen superiority (e.g., Ball & Hourcade, 2011; Dennis et al., 2016; Holzinger et al., 2011; Margolin, Driscoll, Toland, & Kegler, 2013; Murray & Pérez, 2011; Salmerón & García, 2012). Finally, there are studies which point to a discrepancy between learners' preference for digital environments and the actual learning outcomes (e.g., Singer & Alexander, 2017).

The inconsistency in the literature highlights the need for a thorough investigation of the conditions under which computerized learning should be expected to harm performance and those

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that allow eliminating this harmful effect. Our goal in the present study is to shed new light on conditions that lead to lower performance on screen than on paper and those that allow eliminating it, under the same technological conditions. To accomplish this, we used briefly phrased problem solving tasks and compared the results to the pattern of results found with tasks involving comprehension of lengthy texts, thereby generalizing and extending previous research.

In the following sections we delineate three types of explanations for the mixed results. We begin by weighing technological factors versus metacognitive regulation of mental effort. In particular, we elaborate on cues that legitimate shallow rather than in-depth processing in reading comprehension and problem solving. We then consider cognitive load as yet another factor that may contribute to the mixed results. Finally, we outline our study.

1.1. Technological versus regulatory explanations for screen inferiority

Lower performance on screen, when found, has been often explained in terms of technological disadvantages associated with electronic devices, such as screen glare, visual fatigue, and less-convenient navigation along the text relative to parallel task performance on paper (e.g., Benedetto, Drai-Zerbib, Pedrotti, Tissier, & Baccino, 2013; Moustafa, 2016; see Leeson, 2006; for a review). However, empirical evidence has been accumulating to suggest that this explanation is insufficient. First, such lower performance has been found even with the latest e-books and tablets, which are presumed to overcome these technological limitations (e.g., Antón, Camarero, & Rodríguez, 2013; Daniel & Woody, 2013; Lin et al., 2015; see Gu, Wu, & Xu, 2015; for a review). Also pointing in the same direction is the perseverance of a paper preference even among experienced computers' users and young adults (e.g., Baron, 2013; Holzinger et al., 2011; Kazanci, 2015; Kretzschmar et al., 2013; Mizrachi, 2015). Finally, in several studies, lower performance on screen was found in some conditions but not in others (e.g., a pressured vs. loose time frame to complete a task), despite use of the same task on both media and comparable samples (Ackerman & Goldsmith, 2011; Ackerman & Lauterman, 2012; Lauterman & Ackerman, 2014). Technological disadvantages associated with screens should have taken their effect regardless of the condition. These findings hint that the main source for the found lower performance on screen may be cognitive in nature, rather than technology-related.

A potential cognitive explanation that has been gaining empirical support is based on differences in depth of processing between the media. For example, Daniel and Woody (2013) compared reading comprehension in e-textbooks and paper textbooks. While they found no medium effect on test scores, participants in the electronic conditions demonstrated less efficient work—they had to invest more time to achieve similar performance levels. Morineau, Blanche, Tobin, and Guéguen (2005) examined e-books and paper books as contextual cues for retrieval of learned information. They found that the mere presence of the e-book interfered with recall, while the presence of the paper book facilitated it. In addition, users' reports on their experience interacting with computerized environments convey a qualitatively different reading process on computer screens than on paper, involving more interrupted work, attentional shifts, and multitasking, resulting in less time devoted to in-depth reading (Daniel & Woody, 2013; Hillesund, 2010; Liu, 2005). More recently, Mueller and Oppenheimer (2014) compared note taking using a laptop and regular handwriting. They found across three studies that participants who worked on screen used more verbatim note taking, compared to participants who worked on paper, even when participants were instructed not to take verbatim notes. This led to lower success rates for the screen group on recall and conceptual application questions. The authors suggested that working on laptops yielded shallower processing than writing on papers.

This explanation has recently received further support from studies dealing with self-regulated learning. These regulatory processes take place in parallel to the core cognitive processing during the performance of any cognitive task (e.g., storing information in memory during learning, interpreting a road sign during navigation, etc.). The metacognitive framework suggested by Nelson and Narens (1990) emphasizes in particular the central role of reliable monitoring in effective effort regulation. That is, knowledge monitoring guides spontaneous decisions regarding chosen learning strategies and allocation of time to the task. Unreliable monitoring is expected to yield ineffective regulatory decisions. For instance, overconfidence may mislead a learner to think prematurely that her study goal has been achieved and that no further activity is required (see Bjork, Kornell, & Dunlosky, 2013; Winne & Baker, 2013; for reviews). The present study employs a metacognitive framework, with the aim of illuminating conditions under which cognitive and metacognitive processes differ between the two media.

1.2. Media effects on meta-comprehension

Meta-comprehension is the research domain dealing with metacognitive aspects of reading comprehension tasks. In a series of meta-comprehension studies, Ackerman and colleagues found screen inferiority in three measures: the calibration of metacognitive monitoring in the direction of overconfidence; less effective effort regulation; and lower test scores (Ackerman & Goldsmith, 2011; Ackerman & Lauterman, 2012; Lauterman & Ackerman, 2014). Notably, in all these studies there were also conditions in which screen inferiority was not found. For instance, Ackerman and Goldsmith (2011) investigated the effect of time frame on working on screen versus on paper. No significant difference between the media was found under a limited time frame with a sample from a population with a strong paper preference. However, when the participants were free to regulate their learning by themselves, those who studied on screen showed overconfidence and did not benefit from the extra time they invested, while those who studied on paper improved both their monitoring calibration and test scores.

Ackerman and Lauterman (2012) replicated this study with a sample of technology-savvy students, characterized by an attenuated paper preference. They found highly similar screen inferiority, but only under time pressure. Notably, screen inferiority was found only when the time limit was known in advance, but not when participants were interrupted unexpectedly after the same amount of study time. Time pressure has been associated in the literature with compromising on one's goal (Thiede & Dunlosky, 1999). This notion leads us to appreciate the adjustment made by paper participants but not by screen participants. Specifically, participants who worked on paper improved their learning efficiency without compromising on their goals when the task characteristics called for it, presumably by recruiting extra mental effort. Conversely, participants working on screen had similar efficiency with and without time pressure, even though the time frame was known in advance.

Lauterman and Ackerman (2014) replicated the screen inferiority found by Ackerman and Lauterman (2012) under time pressure. Subsequently, they demonstrated two readily applicable methods for overcoming screen inferiority, gaining experience with the challenging learning task and a requirement to generate keywords summarizing the essence of the text after a delay (adapted