Eye movements in print versus on screen

Examining readers' eye movements, on-task attention, metacomprehension, and text comprehension between reading easy and difficult texts in print and on screen

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Recent meta-analyses concluded that reading on screens yields slightly but relevant lower reading comprehension outcomes than reading in print. Findings suggest that this effect especially appears when reading activity demands high level of cognitive effort. Although some previous studies examined eye movement differences between reading media, their results are inconclusive and none of them have experimentally tested the influence of text difficulty. The present ongoing study performed an across-media comparison of readers' eye movements during reading easy vs. difficult texts. Sixty-eight undergraduate students read four expository texts varying in difficulty (low vs. high in coherence) and medium (i.e., a printed booklet and a computer screen) while their eye movements were recorded. In addition, after reading each text, they self-reported their on-task attention, estimated their later performance in a subsequent text comprehension test, and answered the test. Main results showed that fixation duration was longer when reading on the screen than in print, whereas there were no differences in self-reported on-task attention, metacognitive monitoring, and text comprehension scores. We suggest that the students were aware of reading difficulties when reading on screens, so that they increased their processing effort in this medium to overcome the on-screen inferiority.

CCS CONCEPTS • E-learning • Distance learning • Computer-assisted instruction

Additional Keywords and Phrases: Eye-tracking, Reading comprehension, On-screen vs in-print reading, Metacomprehension calibration.

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1 Introduction

Several recent meta-analyses have found significant better comprehension outcomes for reading in print than on screen, (e.g., Clinton, 2019; Delgado et al., 2018). This effect has been suggested to be especially salient when the reading task demands high level of cognitive resources (e.g., when reading under time constraints; Delgado et al., 2018) and to be related to poorer metacomprehension calibration (i.e., the accuracy of one's perception of the level of comprehension attained) when reading on screen (Clinton, 2019). Lessened attentional effort on screen have been also found as one possible cause of this reading medium effect (Delgado & Salmerón, 2021). These suggestions are in line with the Shallowing hypothesis (Annisette & Lafreniere, 2017), which proposes that texts are processed more superficially on screens due to the habits we develop when interacting with texts in this medium.

Given that longer fixations and increased number of fixations are generally associated with increased effort in text processing (e.g., Rayner et al., 2006) and with the use of self-monitoring strategies (e.g., van Gog & Jarodzka, 2013), some recent studies have compared undergraduates' eye movements between reading in print and on screen (e.g., Delgado & Salmerón, 2022; Feis et al., 2021; Jeong & Gweon, 2021; Jian, 2022). However, their results are heterogeneous, hence inconclusive. Further, none of them have directly examined the possible influence of the cognitive demands of the reading task by manipulating text difficulty.

1.1 The present study

In the present study, we compared undergraduate students' eye movements during reading, metacomprehension calibration, self-reported mind-wandering, and text comprehension outcomes by means of a within-participant experimental study in which reading media (print vs computer screen) and text difficulty (easy vs difficult) were manipulated. The participants read two texts in each medium (one easy, one difficult) under time constraints while their eye movements were recorded. After reading each text, they predicted their performance in a subsequent text comprehension test. In addition, they self-reported their on-task attention while reading after completing the experimental tasks in each medium.

We expected that the reading medium effect (i.e., the on-screen inferiority) would appear regardless of the text difficulty, but that it would be especially salient when reading the difficult versions of the texts. According to the idea that reading on screens negatively affects cognitive efforts, as well as based on prior meta-analytic results, we expected increased fixation times in print, as compared to reading on screen, as well as higher self-perceived attentional effort, more accurate metacomprehension calibration, and higher text comprehension outcomes in this medium than on screen.

2 Method

2.1 Participants

Sixty-eight undergraduate students from a large Spanish university participated in the study in exchange for course credit (M_{age} = 19.51 years; *SD* = 1.41; 61 female). Data from six participants were excluded due to low accuracy of the eye-tracking data. Thus, the final sample consisted of 62 participants. All of them had normal or corrected-to-normal vision and no learning difficulties (self-reported).

2.2 Apparatus and materials

Eye-tracker. Students' eye-movements during reading were tracked using the SMI Eye-tracking Glasses v1, a video-based, infrared eye-tracker with a binocular sampling rate of 30Hz, automatic parallax correction, an accuracy of 0.5º over all distances, and a gaze tracking range of 80º horizontal and 60º vertical. The system was 3-point calibrated before reading each text. For the sake of ecological validity, we did not use a chin rest. The participants were thus free to move during reading, although we asked them to do it as little as possible.

Texts. We used four expository texts about biology-related topics. Each text had an easy and a difficult version varying on internal coherence (516-1149 and 427-691 words, respectively). All texts have been used and validated in previous research on reading comprehension (Ozuru et al., 2009, 2010; Vidal-Abarca et al., 2002). On-screen texts were full-page displayed on a 21-inch full HD screen, and printed texts were read in a A4-size booklet held on a stand. They had the same formatting and size in both media.

2.3 Measures

Eye fixation measures. Three eye movement measures were calculated at texts' paragraph level by averaging number of fixations and fixation times (in milliseconds) per character: 1) Fixation total time, 2) Number of fixations, and 3) Fixation duration; each computed separately for first-pass and second-pass reading. First-pass reading of a paragraph consisted of all the fixations that occurred when the participant read the paragraph completely for the first time. Thus, it also included fixations that occurred when the participant returned to a paragraph that had not fully read before his/her gaze moved to another part of the text. Second-pass reading consisted of fixations that occurred when the reader returns to a paragraph that had already been fully read (Hyöna et al., 2003). We thus analyzed 6 eye movement measures per participant in total.

Text comprehension. Students' comprehension of each text was measured by 10 open-ended questions (6 inferential, 4 literal) that have been also utilized in previous studies using the same texts. In order to increase the reliability of this measure, 8 questions per text were finally included. Reliability was good ($\omega = .82$).

Metacomprehension calibration. After reading each text, participants predicted their performance on the subsequent comprehension questions by indicating the percentage of questions they estimated that they would answer correctly. A calibration index for each participant per text was computed by subtracting the actual percentage of correct answers from his/her prediction. Negative values indicated underestimation of their subsequent performance, and positive values indicated overconfidence.

Mindwandering. After reading the two texts in each medium, participants completed a post-task mindwandering questionnaire (Sanchez & Naylor, 2018) consisting of five Likert-scale items on how attentive they were to the reading task (e.g., "While reading the text, how often did you notice your mind wandering to thoughts other than the text?"). Each item was rated from 1 ("Almost never") to 6 ("Almost always"). Reliability was acceptable ($\omega = .74$).

Covariates. Participants' reading comprehension skill, sustained and selective attentional capacity, short-term verbal memory, prior knowledge on biology, medium preference for study purposes, and situational interest in each text (i.e., interest in the texts' content once read) were measured in order to control for potential covariates.

2.4 Procedure

The students participated in a single 2.5-hour session. They first completed the standardize tests assesing attention, short-term verbal memory, and reading comprehension skill, and they then answered the prior knowledge questionnaire. After reading a practice text (with 2 comprehension questions), they read two texts (one easy, one difficult) in one medium. After each text, they predicted their performance in the subsequent comprehension test and then accessed and answered the questions. After completing the first two texts and sets of questions, they completed the on-task mindwandering questionnaire. They then repeated the same procedure with the remaining two texts in the other medium. Lastly, they reported their medium preference and some demographic data. They were informed that they had time limitations to read each text, and texts and reading media were counterbalanced across participants.

2.5 Data analysis

We performed linear mixed-effects models (LMM) to analyze the influence of reading medium and text difficulty on the dependent measures described above. Medium and text difficulty were included as fixed effects in all cases. Participant and text topic were included as random effects when examining text comprehension scores, self-reported mindwandering, and calibration accuracy. In the case of the eye movements, texts paragraph was also included as random effect. Random intercepts and fixed slopes were set in all cases based on models' goodness of fit comparisons. Those covariates that demonstrated to significantly predict any of the dependent measures also based on LMM analyses were included in the model for that measure. Preliminary results are presented.

3 RESULTS

3.1 Eye movements during reading

LMM including the main effect terms of medium and text difficulty showed better goodness of fit than those including the interaction term in all cases, indicating that there was no interaction effect of medium and difficulty on any of the eye movement measures. In addition, there was no main effect of medium and difficulty on *Number of fixations* and *Fixation total time,* both during first-pass and second-pass reading, all ts < 1.47, ps > .17. However, we found a main effect of medium on *First-pass fixation duration* and on *Second-pass fixation duration*, although this effect was significant only in the latter case, $t(65.85) = 1.86$, $p = .07$ and $t(743.67) = 2.32$, $p = .02$, respectively. These results indicated that participants tended to fixate longer on screen, especially when re-reading the text paragraphs (see Figure 1).

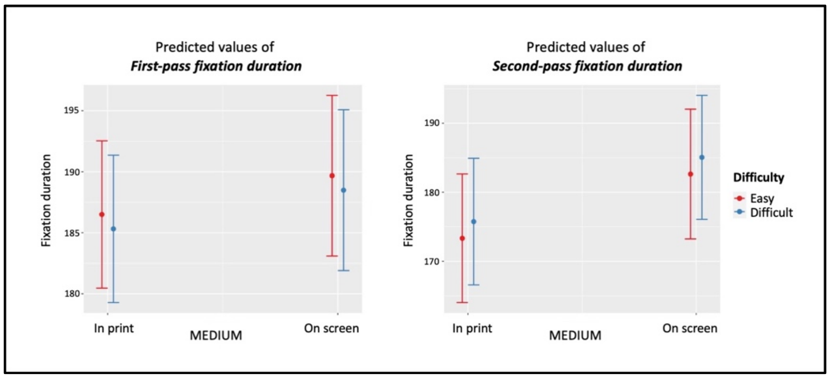

Figure 1: Predicted values for *Firs-pass* and *Second-pass fixation duration* in milliseconds

3.2 Mindwandering, calibration, and text comprehension scores

Similarly, LMM including the main effect terms of medium and text difficulty showed best goodness of fit in all cases, indicating the absence of interaction effects on participants' mindwandering, calibration index, and text comprehension scores. With respect to the main effects, we only found a significant effect of text difficulty on text comprehension scores, $t(176.61)= -2.37$ $p = .02$, indicating better comprehension for the easy texts. There was no effect of text difficulty on mindwandering and calibration index, both ts < 0.44, ps > .65, and no effect of medium on any of these three dependent measures, all ts < 0.74, ps > .46.

4 DISCUSSION

Contrary to our expectations, but in line with findings in the studies conducted with tablets as digital devices by Jeong and Gweon (2021) and Feis et al. (2021), our preliminary results showed longer fixation duration when reading on the computer screen than in print. In addition, also unexpectedly, participants' text comprehension scores, self-reported mindwandering, and calibration accuracy were similar in both media regardless of text difficulty. These results contrast with previous findings showing better outcomes when reading in print, not only in text comprehension (e.g., Delgado et al., 2018), but also in calibration accuracy (Clinton, 2019) and on self-reported on-task attention during reading (Delgado & Salmerón, 2021). It is noteworthy that text comprehension scores were similar across media in spite of increased fixation duration on screen. As a possible explanation, recent studies on undergraduates' subjective perceptions about reading on screens have shown that they mostly perceive some cognitive difficulties in this medium (Mizrachi et al., 2018). Moreover, the massive practice of digital reading for study purposes due to distance learning during the COVID-19 pandemic could have been increased this perception or even helped students develop reading strategies to overcome the on-screen difficulties. Thus, we suggest that the students in our study increased their cognitive effort when reading on screen in an experimental setting, especially when re-reading, which helped them perform similarly to reading in print.

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