Reading and Writing
https://doi.org/10.1007/s11145-022-10328-9

Is it the size, the movement, or both? Investigating effects of screen size and text movement on processing, understanding, and motivation when students read informational text

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Accepted: 22 June 2022

Abstract
This study focused on the potential effects of screen size (smartphone vs. tablet) and text movement (scrolling vs. paging) on integrated understanding of text information, strategic backtracking, and intrinsic reading motivation when Norwegian university students read an informational text on either a smartphone or a tablet by either scrolling or paging. We expected that paging would lead to better integrated understanding of the text and more strategic backtracking than scrolling. Also, we explored whether scrolling would lower the intrinsic motivation for performing the reading task, and whether there were interactional effects of screen size with text movement on integrated understanding, strategic backtracking, and intrinsic motivation. Results indicated that students tended to obtain better integrated understanding when paging than when scrolling, and that those who paged through the text displayed more strategic backtracking than those who scrolled. Further, scrolling on a tablet led to a more positive reading experience than paging on a tablet or scrolling on a smartphone. In addressing two basic aspects of the reading context and the reading activity when students read digital text for understanding, this study provides new insights into the complex digital reading puzzle that may have both theoretical and practical implications.

Keywords Digital reading · Reading on mobile devices · Text understanding · Reading strategy · Reading motivation

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Published online: 27 August 2022

Introduction

During the last decade, researchers in learning and literacy have shown renewed interest in the difference between print based and digital reading, with several meta-analyses documenting that readers generally gain better understanding when reading a text on paper than when reading the same text on a screen (Clinton, 2019; Delgado et al., 2018; Kong et al., 2018). At the same time, however, less attention has been devoted to the possibility that basic differences within digital reading may influence how readers engage with and understand textual information (Baron, 2021a). Two such basic differences concern the size of the screen and the way readers move through the text. People increasingly read for different purposes on mobile digital devices, in particular, smartphones and tablets (Kammerer et al., 2018; Mackey, 2020). There are differences between mobile devices in terms of screen size that could matter for several aspects of reading, including the ability to create an integrated understanding of the materials, yet such potential effects are currently poorly understood (Baron, 2021a). Likewise, the way readers move through text on such devices, in particular by scrolling or paging, has been highlighted as a potentially influential factor in readers' comprehension performance (Baron, 2021a, b). Finally, the possibility exists that these two basic differences within digital reading, that is, screen size and text movement, may influence reading comprehension not only individually but also collectively (Sanchez & Goolsbee, 2010). Gaining a better understanding of these issues seems like an important agenda for researchers in digital reading because they concern essential aspects of the reading context and the reading activity (Coiro, 2021).

The present study contributes uniquely to this area of research by investigating the effects of screen size (smartphone vs. tablet) and text movement (scrolling vs. paging) in one and the same study. Also, no prior study has investigated the effects of these aspects of digital reading on readers' integrated understanding of text information as well as on their strategic approach to text reading and motivation for performing the reading task. Before we further specify the questions and hypotheses that guided our research, we present the theoretical grounding of our study and review prior research on the effects of screen size and text movement on reading comprehension. Because we also examined potential effects on readers' strategic approach and motivation in the present study, our background analysis also contains brief discussions of prior work on strategic backtracking and task-based intrinsic reading motivation.

Theoretical and empirical background

Conceptual framework

Digital reading is a goal-directed and situated activity involving the construction of meaning from different types of texts presented in a digital format. A simple, yet powerful, heuristic for thinking about reading comprehension was introduced by the Rand Reading Study Group (e.g., Snow, 2010; Snow & Sweet, 2003), distinguishing between the reader, the text, the reading activity, and the sociocultural context in which reading takes place. Building on this heuristic, Coiro (2021) recently presented a multifaceted heuristic of digital reading that also framed the current study. She proposed that readers varying in cognitive capabilities, reading and language competencies, reading dispositions and motivation, and sociocultural identities engage with digital texts ranging from literary to augmented texts in performing reading activities ranging from single text activities to digital creation activities. Further, these reader, text, and activity dimensions of digital reading were supposed to interact within a context consisting of four elements: the medium or platform, the contextual design, the contextual community, and the response format.

Within the wide spectrum of digital reading experiences encompassed by Coiro's (2021) multifaceted heuristic, we conceptualized the reader in terms of individual differences in cognitive capacity (i.e., working memory) and reading competency (i.e., reading comprehension), the text as an informational, on-screen text, and the reading activity as a single text activity. With respect to the context, we conceptualized the medium/platform as the reading of multiple pages on a mobile digital device, the contextual design as untimed, individual reading of other-selected text in order to accomplish a particular task goal, the contextual community as school-based, and the response format as a combination of video recorded response, extended constructed typed response, and multiple choice response. Although a host of variations with respect to reader, text, activity, and context can be expected to influence the processes and outcomes of digital reading (Coiro, 2021), we experimentally manipulated only two elements within this conceptualization in the current study: the contextual medium/platform element of digital device to create systematic variation with respect to screen size, and the reading activity element of single text activity to create systematic variation in how readers moved through the text. In doing this, we aimed to provide new insights into the functions of these, arguably small, but fundamentally important pieces in the complex digital reading puzzle.

When digital texts are longer than a screen page, readers can access additional passages of the text in different ways, with scrolling and paging being the most common. On mobile devices, both scrolling and paging are typically done with the fingers, although a touch screen pen or stylus can also be used. During reading, scrolling involves a continuously variable transportation to additional text, with the amount of additional text being accessed in each movement controlled by the reader. In contrast, paging involves accessing a fixed amount of additional text equal to the screen size in each movement, with this amount being predetermined and, thus, not controlled by the reader. Theoretically, scrolling is more challenging as far as comprehension is concerned because it distorts the spatial layout and therefore makes it more difficult to encode textual information in a two-dimensional space constrained by a page (Piolat et al., 1997). In contrast, paging, which is analogous to moving through a conventional printed text, presumably makes it easier to create a mental representation that includes information about the spatial location of text, that is, a form of cognitive map of where particular content is located on the page (e.g., in a paragraph in the middle of the page). Importantly, such a cognitive map is, in turn, supposed to support comprehension processes and outcomes (Baron, 2021a, b; Piolat et al., 1997). In other words, the "where" may serve the "how" and "what" (cf., Baccino & Pynte, 1994), such as when the mental marking and subsequent representation of where important content is located help readers relocate and reprocess such content as well as draw inferences that connect content across the text to form an integrated understanding. Consequentially, scrolling may represent a particular challenge when the response format requires an integrated understanding of the text content (Piolat et al., 1997; Sanchez & Wiley, 2009).

Readers access digital texts on mobile devices that vary with respect to screen size, such as smartphones and tablets. On smaller screens, encoding and representation of the spatial location of text may be more challenging, simply because the two-dimensional space is smaller, and this challenge may be particularly pronounced when scrolling on smaller screens, which seems to be the rule rather than the exception when reading on smartphones (Baron, 2021a). Thus, when reading for understanding, scrolling on a smaller screen may be the least favorable condition for creating a cognitive map of "where" that could scaffold the integration of information across the text (Sanchez & Goolsbee, 2010). Relatedly, scrolling on a smaller screen may make it particularly difficult to relocate and reprocess content that is considered important, which therefore may be avoided by the reader. Finally, the increased challenge associated with scrolling on a smaller screen may have negative emotional and motivational consequences, with readers possibly more prone to dislike reading for understanding in this condition compared to other options. Presumably, smaller screens may also lead to more dislike in and of themselves (i.e., independent of text movement) because smaller font size may increase perceptions of fatigue during reading. Of course, the notion that scrolling on smaller screens may be particularly detrimental to processes and outcomes when reading for understanding implies a possible interaction between screen size and screen dynamics (i.e., text movement) that to our knowledge has previously not been investigated.

To better understand how screen size and text movement, as well as their interaction, may influence digital reading, focusing on the outcome of reading in terms of text comprehension may provide only part of the picture. As indicated above, readers' text processing, and in particular their ability to relocate and reprocess previously read text as needed, may be influenced by these features of digital reading. Such "strategic backtracking" (Garner, 1987) has been considered important in several conceptualizations of reading (e.g., Afflerbach & Cho, 2009; Garner, 1987; Pressley & Afflerbach, 1995: Pressley & Harris, 2006), especially because it may help readers compare, contrast, and integrate information across different parts of the text. Conversely, failure to strategically backtrack to reprocess previously read text may have negative consequences in the form of a less coherent mental representation of textual content.

Further, emotional and motivational consequences need to be considered in addition to cognitive ones. In particular, variation in elements of digital reading may affect readers' task-based intrinsic reading motivation, which refers to their affective involvement in the reading task (Schiefele & Schaffner, 2016). According to reading motivation researchers (e.g., Schaffner et al., 2013; Schiefele et al., 2012), this kind of positive affective reading experience is not only important in itself but also because it increases the likelihood that readers approach similar reading tasks with enthusiasm in the future. In turn, a larger amount of reading is likely to increase reading competency over time (Schiefele et al., 2012).

Prior research

Regarding how readers move through the text, several experimental studies have compared scrolling and paging with respect to aspects of reading comprehension (Fukaya et al., 2011; Imai & Omadani, 2007; Piolat et al., 1997; Sanchez & Wiley, 2009; Wästlund et al., 2008). For example, Piolat et al., (1997), in a study including French psychology undergraduates, had participants read a 574-word informational text on a desktop computer and afterwards write a summary of the text on paper, with participants randomly assigned to read the text by scrolling by means of the scroll bar or by paging by clicking on page numbers at the right side of the screen. The scoring of the written summaries was based on the number of paraphrases in the summaries of both important ideas and details in the text. Results showed that participants in the paging condition received somewhat higher scores on both important ideas and details in the summaries than did those in the scrolling condition, although none of these differences were statistically significant.

In two experiments, Wästlund et al. (2008) had Swedish university students in psychology read one 1000-word text in the scrolling condition and one comparable 1000-word text in the paging condition (i.e., within-subjects, counterbalanced). Reading was done on a desktop computer and the comprehension of each text was assessed with a 4-6-item multiple-choice test (the genre of the texts was not specified). In none of these experiments was any difference between the scrolling and paging conditions observed on the multiple-choice tests, although performance on a secondary task (reaction time to pop-ups) indicated that cognitive load was higher in the scrolling than in the paging condition.

Using a between-subjects design (scrolling vs. paging) with American university students in psychology, Sanchez and Wiley (2009) conducted two experiments in which participants read informational texts consisting of 2500 (Exp. 1) and 3500 words (Exp. 2) on a computer (type not specified) in order to write short argumentative essays based on the texts. These essays were scored according to the number of critical concepts in the texts (5 in Exp. 1, 8 in Exp. 2) that were included in the essays. Taken together, the experiments showed that paging led to higher essay scores than did scrolling, with high working memory capacity seemingly needed to compensate for the negative effects of scrolling on performance.

In a within-subjects experiment in which Japanese corporate workers read four informational texts consisting of 1500 words each (approx. 750 English words) on smartphones (two using scrolling, two using paging, counterbalanced), Fukaya et al. (2011) found that reading comprehension was somewhat better in the paging than in the scrolling condition, yet not statistically significantly so. In that study, reading comprehension was measured with 10 fill-in-the-blank items for each text, which means that only exact memory for factual details was measured.

While we were not able to locate any prior study on this issue that included emotional or motivational outcome measures, Piolat et al. (1997) reported some relevant processing data in the experiment described above. Thus, these authors observed a nonsignificant trend consistent with the hypothesis that paging would lead to more backtracking to previously read text than would scrolling. Further, a complementary finding was that participants who paged were better able to determine where in the text specific content was located (when probed after reading), with such mental representation of spatial information probably making it easier for them to draw on spatial cues in backtracking to preceding paragraphs during reading.

Regarding potential effects of screen size on aspects of reading comprehension, the current research base is limited and somewhat inconsistent. For example, Singh et al. (2011) compared comprehension performance when adult Canadian readers read the privacy policies of 10 popular websites (e.g., Wikipedia, You Tube) by scrolling on either a desktop computer or a smartphone-sized screen. Using a cloze test to measure comprehension, these authors found that performance was much lower when reading on the smaller screen, presumably because more scrolling was needed to access additional text in this condition (see also, Nielsen, 2011). In addition, Singh et al. (2011) found that participants reportedly preferred the larger screen when completing these quite complex digital reading tasks for understanding.

Likewise, Sanchez and Goolsbee (2010) found that American psychology undergraduates who read three approximately 500-word informational texts on a desktop computer outperformed those who read the same texts on a smartphone-sized screen (between-subjects) on a factual recall test. Further, these authors found that when they forced participants to scroll more on the smaller screen (by making the font size larger) their text recall was poorer, which suggests that scrolling on smaller screens may be particularly challenging when reading for understanding (given the text length, no scrolling was needed on the desktop computer in this experiment).

In a study by Hsieh et al. (2016), however, no difference was found on a 4-item multiple choice test of reading comprehension between Taiwanese college students who read an informational text consisting of 1540 words (approx. 1000 English words) by paging on either tablets or smartphones (between-subjects). Participants in this study scored higher on a visual fatigue questionnaire after reading on smartphones than after reading on tablets.

Sheen and Luximon (2021) had university students from Hong Kong who were not native speakers of English read history texts in English on tablets and smartphones by paging, using a within-subjects design. The length of the texts was not specified in this study, and the comprehension of the texts was measured with short multiple-choice tests. Screen size was not found to influence reading comprehension scores. However, reading on the smallest screen (i.e., the smartphone) was associated with more backtracking to previous pages during reading, and participants generally expressed that they liked the smartphone least when reading the academic texts.

Finally, Moran (2016) reported on an experiment in which 276 participants read easy, shorter (mean length = 404 words) and difficult, longer (mean length = 988 words) informational texts by scrolling on computers and smartphones (within-subjects design). The results showed slightly higher scores on multiple-choice comprehension tests for reading on smartphones; a difference that was reduced when the texts were more difficult and longer.

In summary, this review of prior empirical work demonstrates that there is plenty of room for increased clarity within this area of research. First, research on text movement as well as on screen size has mostly used short texts (< 1000 words), which may be less sensitive to detecting potential effects of these digital reading factors on processes and outcomes of reading. Second, effects of these factors may be more pronounced on measures of integrated text understanding than on measures of piecemeal, factual understanding, which have mostly been used in this area of research. Third, measures of processing and motivational outcomes were essentially lacking in the studies we reviewed. Fourth, prior research has not investigated the effects of text movement and screen size in one and the same study, such as when comparing scrolling and paging by finger touch manipulation on a smartphone versus a tablet, which would capture ubiquitous ways of accessing text information among modern readers.

The present study

We investigated potential effects of screen size and text movement on integrated understanding of text information, strategic backtracking, and intrinsic reading motivation when Norwegian university students read a longer, informational text on either a smartphone or a tablet, using finger touch manipulation to access additional text by either scrolling or paging. Specifically, the following three questions guided our research:

1. Does text movement (i.e., scrolling vs. paging) influence readers' integrated understanding of text information, and does screen size (smartphone vs. tablet) moderate their integrated text understanding?
2. Does text movement (i.e., scrolling vs. paging) influence readers' backtracking to previously read text, and does screen size (smartphone vs. tablet) moderate their backtracking?
3. Does text movement (i.e., scrolling vs. paging) influence readers' motivation to perform the reading task, and does screen size (smartphone vs. tablet) moderate their motivation?

Regarding the effects of text movement, we built on theoretical assumptions and preliminary empirical work (Baccino & Pynte, 1994; Baron, 2021b; Piolet et al., 1997; Sanchez & Wiley, 2009) in expecting that paging would lead to better integrated understanding of the text as well as more strategic backtracking to check or reread content located in paragraphs on previously read pages (main effects). At the same time, we explored the possibility that the distance of the movement might vary between scrolling and paging, in particular, whether scrolling might lead to more distal backtracking because of the ease (if not precision) with which text may be moved by means of the scrolling procedure. Regarding a potential effect of text movement on motivation, we could not ground any hypothesis in prior empirical work. Still, based on the assumption that scrolling is more challenging and also requires higher cognitive load when reading for understanding (Baron, 2021b; Piolot et al., 1997; Wästlund et al., 2008), we considered it plausible that scrolling would lower the intrinsic motivation for performing the reading task (main effect).

In addition to these potential main effects, we entertained the possibility that scrolling on the smaller screen (i.e., when reading on a smartphone) would be particularly challenging when reading for understanding and therefore lead to poorer integrated understanding, less strategic backtracking, and lower intrinsic reading motivation than the other conditions (interaction effects). Although this possibility has not been assessed directly in prior research, scrolling on smaller screens may be particularly challenging due to increased difficulties creating a cognitive map of the text that might scaffold integrated understanding as well as help readers relocate and reprocess previously read information (Baron, 2021b; Piolat et al., 1997). As a consequence, readers might also like reading for understanding less when using a smaller screen.

Finally, we measured participants' cognitive capacity in terms of working memory and reading competency in terms of basic reading comprehension skills in this study. This gave us the opportunity to control for potential effects of these individual difference variables on the processes and outcomes of digital reading that we targeted. Both working memory and reading comprehension skills may influence these processes and outcomes (e.g., Bohn-Gettler & Rapp 2014; McNamara & Magliano, 2009; Prat et al., 2016), and we therefore wanted to ensure that potential effects of our experimental manipulations were independent of them.

Method

Participants

The sample consisted of 145 students (82.1% female) enrolled in bachelor and master level programs in education, teacher education, and special education at a large public university in southeast Norway. Their mean age was 26.11 years (SD = 5.66), and 81.4% had Norwegian as their first language (the rest were bilingual). Because the topic of the text that they read was the physiology of sexuality (see *Materials* below), we asked them to self-report their knowledge about human physiology on a 10-point scale (1 = *no knowledge*, 10 = *expert*) before reading the text. A mean score of 4.24 (SD = 1.76) indicated that their perceived knowledge about this domain was relatively low. Everyone received a gift card worth approximately 25 USD for participating in the study. The Norwegian Social Science Data Services evaluated the study and found the collection and handling of data to be in accordance with the Personal Data Registers Act.

Materials

Text and experimental manipulations

The text that all participants read was an extended version of an experimental text created and used by Latini et al. (2020). The text, which was titled "The Physiology of Sexuality," was based on various authentic sources, including popular science texts, scientific journal articles, and an introductory psychology textbook. These materials were adapted in terms of length and language and integrated into one single 17-paragraph text consisting of 1492 words (including figure captions) and three figures. The issues discussed across the 17 paragraphs included the production of sex hormones, the phases of the sexual response cycle, brain activity during orgasm, causes and treatment of sexual problems, the relationship between sexual pleasure and pain, and research on sexual arousal. Source information was presented in the upper right corner, with the text said to be taken from a well known Norwegian popular science website (forskning.no). Because students' engagement in experimental reading tasks is often lower than desirable (Bråten et al., 2018), we chose this topic for its potential relevance and importance to the lives of our participants. The readability estimate for the text based on word and sentence length was 55, indicating that the difficulty level was comparable to that of specialized, academic literature (Björnsson, 1983). An English version of the entire text is included in the online supplemental materials.

The screen size was manipulated between participants, such that participants (randomly assigned) read the text on either a smarthphone or a tablet. The smartphone was a Samsung Galaxy A02s (SM-A025G/DSN) with a 6.5" screen at a resolution of 720×1600 pixels, and the tablet was a Lenovo Tab M10 FHD Plus (TB-X606F) with a 10.3" screen at a resolution of 1920×1200 pixels. The text was read as a PDF file with 14 point Verdana using the Acrobat Reader for PDF application. Participants could use their fingers to zoom in and out on both the smartphone and the tablet screen. Both devices used the Android operating system (system version 10), which allowed for comparable layouts and use of the same applications.

In addition to this screen size manipulation, we randomly assigned participants to read the text by either scrolling or paging with their fingers. In the scrolling condition, the text was presented as a single, unitary page that participants could scroll forwards and backwards (i.e., up and down), and in the paging condition, the text was presented as seven distinct pages without any page numbers that could be moved forwards and backwards (i.e., up and down) one at a time.

Dependent measures

Integrated Text Understanding. We measured participants' integrated understanding of text information by means of post-reading written reports explaining the similarities and differences between men and women's sexual responses. We identified 11 unique idea units concerning similarities and differences between males and females that could be inferred from the text by integrating information across paragraphs. Three of these idea units concerned only similarities (e.g., males and females experience four phases during sexual activity), six idea units concerned only differences (e.g., some females may experience multiple successive orgasms whereas males are temporarily unable to achieve a new orgasm), and two idea units concerned both similarities and differences (e.g., although many females perceive that lack of sexual desire is due to hormone deficiency whereas males dissatisfied with their sex lives often attribute this to their partner's lack of sexual desire, both males and females have been shown to profit from androgen therapy).

For each of these 11 idea units, participants were awarded 0–2 points, such that their scores on the entire measure could vary from 0 to 22 (only the total scores were used in the statistical analyses). A score of 0 was given when an idea unit was not represented in the written report, a score of 1 was given when an idea unit was represented but was not elaborated or did not include a comparison of males and females, and a score of 2 was given when the idea unit was represented and was elaborated or included a comparison of males and females. Of note is that men and women's sexual responses were not explicitly compared in the text, such that similarities and differences had to be inferred by drawing bridging inferences across paragraphs and pages to establish coherence or intratextual integration (Magliano & Millis, 2003; McNamara, 2021). Consequently, high scores on this measure can be assumed to represent an integrated understanding of the text content. To minimize the influence of participants' writing skills, common aspects of writing quality such as mechanics, grammar, syntax, and organization were not taken into account when scoring the written reports. Further description of the scoring system is included in the online supplemental materials.

Blind to experimental conditions, the first two authors scored all written reports. First, they coded 15 reports collaboratively. Next, they coded a random selection of 30 reports independently. The independent coding resulted in a high interrater reliability estimate (Cohen's kappa = 0.82) and a high correlation between the raters' total scores (Pearson's $r = .94$). All disagreements were solved in discussion, and the same authors scored the remaining reports separately.

Backtracking. To measure backtracking during reading, we recorded how participants moved through the text by means of the A2 Screen Recorder Application. The first and second authors watched all the recordings and coded all the instances where participants backtracked (by scrolling or paging) to check or reread something in a paragraph located on a previously read page, using a criterion of at least a 2-second stop on that page to ensure that participants were not just passing it on the fly. First, the two authors coded the backtracking of 15 participants collaboratively. Then, they coded the backtracking of 30 randomly selected participants independently. The independent coding resulted in a high interrater reliability estimate (Cohen's Kappa = 0.87) and a high correlation between the two raters' total number of backtracking instances (Pearson's $r = .81$). All disagreements were solved in discussion, and the same two authors scored the remaining screen recordings separately.

In addition to computing the total number of backtracking instances for each participant, we computed the average distance of each participant's backtracking in page units, such that a participant who scrolled or paged back two pages on average to check or reread previously read text would get a score of 2. In this way, we were also able to explore whether the experimental conditions might differ with respect to more distal backtracking.

Task-based Intrinsic Reading Motivation. To measure participants' intrinsic motivation to perform this particular reading task, we administered a 5-item inventory developed by Bråten et al. (2017). Immediately after reading, participants used a 5-point scale (1 = does not fit at all, 5 = fits very well) to rate to what extent they experienced reading the text as exciting, interesting, fun, attractive, and enjoyable, respectively. Thus, this inventory can be assumed to capture participants' positive, affective involvement in reading (Latini et al., 2020; Schiefele & Schaffner, 2016). Internal consistency reliability (Cronbach's alpha) was 0.87.

Control variables

Working Memory Capacity. Working memory capacity was measured with a Norwegian adaptation of Swanson and Trahan's (1992) Working Memory Span Test that has been validated in several previous studies with adult readers (e.g., Bråten et al., 2022; Delgado et al., 2020). Twelve sets of unrelated sentences, varying from two to five sentences in each set, were read aloud to participants. After each set, participants first answered a comprehension question about one of the sentences and then wrote down the final word of each sentence in the set on the same response form. In this way, simultaneous processing and storage of information were required by the working memory task (Baddeley, 2001). Participants' scores were based on the total number of correctly recalled final words across all 12 sets, with the possible maximum score being 42. Points were only given for the final words in a set if the comprehension question had been answered correctly. Internal consistency reliability (Cronbach's alpha) was 0.87.

Reading comprehension skills. Participants' basic reading comprehension skills were measured by means of a Norwegian adaptation of a cloze test created by Gellert and Elbro (2013). This adaptation has been validated in several previous studies with adult readers (e.g., Latini et al., 2019, 2021). It consisted of five expository and five narrative texts with a total length of 1340 words that had 41 word gaps altogether (i.e., possible maximum score = 41). There were four alternative words for each gap and selection of the right word always required some form of inferencing (Gellert & Elbro, 2013). Participants were given 10 minutes to refill as many word gaps as possible. The internal consistency reliability (Cronbach's alpha) was 0.89.

Procedure

The data collection took place in a computer lab at the university, with all data collected by the first author during 60-minute sessions with 2–5 participants per session. All participants in the same session were in the same experimental condition, that is, smartphone/scrolling, smartphone/paging, tablet/scrolling, or tablet/paging. The working memory task was group-administered orally before participants completed a demographic survey, the reading comprehension assessment, and the perceived knowledge item independently in this order. All these assessments were paper-and-pencil tests. Before starting reading the text in their respective condition, participants read the following instruction on paper:

> *You are going to read an informational text of about 1500 words on the physiology of sexuality. Most spend about 10 minutes reading this text. Afterwards, you are going to write a brief report based on this text, in which you explain similarities and differences between men and women's sexual responses. You may go back and forth in the text as much as you want while reading, but you will not be able to look back to the text while writing your report.*

Smartphones or tablets (depending on the condition) were then handed out and participants were informed that they could access the text by clicking on a text icon in the middle of the screen and that they could move within the text by scrolling or swiping. The screen recorder was started as soon as they began reading, and when they finished reading, they closed the text and went back to the home screen.

As soon as participants signaled that they had finished reading, they accessed a web based questionnaire through a link on the screen of an available desktop computer. After having responded to the five items concerning task-based intrinsic reading motivation, participants read the following writing prompt:

> *Explain similarities and differences between men and women's sexual responses based on the text you just read. You can spend as much time as you want on this writing task. It is important that you express yourself as completely and elaborately as you can.*[1]

Participants completed their report in a dedicated textbox with no word limit that was available below the writing prompt and submitted the report to a server when finished.

Results

Table 1, which includes descriptive information and zero order correlations for all measured variables for the entire sample, shows that both control variables (i.e., working memory and reading comprehensions skills) were positively correlated with integrated text understanding. However, the control variables were not statistically significantly correlated with any other dependent measure. Descriptive information about the control variables as well as the dependent measures for the four subgroups differing in regard to screen size (smartphone or tablet) and text movement (scrolling or paging) is shown in Table 2. The four subgroups were used as an independent variable in a one-way analysis of variance (ANOVA) with working memory and reading comprehension skills as the dependent variables. Neither working memory, $F(3, 141) = 1.55$, $p = .203$, $\eta^2 = 0.032$, nor reading comprehension skills, $F(3, 141) = 1.00$, $p = .396$, $\eta^2 = 0.021$, differed statistically significantly between the subgroups. Based on these preliminary analyses, the control variables of working memory and reading comprehension were included as covariates only in the analysis using integrated text understanding as a dependent variable (Tabachnick & Fidell, 2014).

Table 1 Descriptive statistics and zero-order correlations for all measured variables

Variables	1	2	3	4	5	6
1. Working memory	-					
2. Reading comprehension skills	0.352**	-				
3. Integrated understanding	0.278**	0.278**	-			
4. Backtracking	−0.049	−0.045	0.147	-		
5. Distal backtracking	0.090	0.107	−0.004	−0.091	-	

[1] This writing prompt is similar to the one used by Latini et al. (2020).

Table 1 Descriptive statistics and zero-order correlations for all measured variables

Variables	1	2	3	4	5	6
6. Task-based intrinsic reading motivation	−0.119	0.005	0.069	0.132	−0.032	-
M	23.49	27.48	8.45	3.01	2.49	3.62
SD	7.98	6.89	4.09	2.51	1.61	0.87

Note. $n=145$. *$p<.05$, **$p<.01$

Table 2 Descriptive statistics (means and standard deviations) for subgroups differing with respect to screen size and text movement

	Smartphone		Tablet	
	Scrolling ($n=38$)	Paging ($n=32$)	Scrolling ($n=36$)	Paging ($n=39$)
Working memory	25.50 (9.26)	21.41 (7.01)	23.42 (8.06)	23.31 (7.11)
Reading comprehension	28.89 (7.01)	27.88 (7.55)	26.81 (5.82)	26.41 (7.13)
Integrated understanding	7.82 (4.13)	8.69 (4.47)	8.22 (3.44)	9.08 (4.31)
Backtracking	2.87 (2.43)	3.50 (3.05)	2.11 (1.41)	3.56 (2.71)
Distance backtracking	3.01 (1.73)	2.06 (1.45)	2.74 (1.86)	2.13 (1.19)
Intrinsic motivation	3.45 (0.90)	3.69 (0.86)	3.92 (0.80)	3.45 (0.86)

To address our first research question, regarding potential effects of our experimental manipulations on integrated text understanding, we performed a 2×2 between-subjects analysis of covariance (ANCOVA) with screen size (smartphone, tablet) and text movement (scrolling, paging) as independent variables and integrated text understanding as the dependent variable, including working memory and reading comprehension skills as covariates. Results of evaluation of the assumptions for performing ANCOVA were satisfactory. Neither the main effect of screen size (smartphone: $M=8.14$, $SD=3.88$; tablet: $M=8.78$, $SD=3.87$; $F(1, 139)=0.97$, $p=.326$, $\eta_p^2 = 0.007$), nor the main effect of text movement (scrolling: $M=7.86$, $SD=3.86$; paging=9.06, $SD=3.88$; $F(1, 139)=3.43$, $p=.066$, $\eta_p^2 = 0.024$), was statistically significant. Further, the interaction between screen size and text movement was not statistically significant, $F(1, 139)=0.19$, $p=.667$, $\eta_p^2 = 0.001$. In this analysis, both control variables uniquely adjusted the score on the measure of integrated understanding, with $F(1, 139)=7.03$, $p=.009$, $\eta_p^2 = 0.048$, for working memory, and $F(1, 139)=6.65$, $p=.011$, $\eta_p^2 = 0.046$, for reading comprehension. Although not statistically significant, we note a clear trend in the expected direction for text movement, with paging leading to higher scores on integrated text understanding than scrolling.

To address our second research question, regarding potential effects of our experimental manipulations on backtracking during reading, we first performed a 2×2 between-subjects ANOVA with total number of backtracking instances as the dependent variable. Results did not show any statistically significant main effect of screen size (smartphone: $M=3.18$, $SD=2.47$; tablet: $M=2.84$, $SD=2.47$; $F(1, 140)=0.70$, $p=.404$, $\eta_p^2 = 0.005$). However, as expected, paging led to more backtracking instances than scrolling (scrolling: $M=2.49$, $SD=2.46$; paging=3.53, $SD=2.48$; $F(1, 140)=6.43$, $p=.012$, $\eta_p^2 = 0.044$). The interaction between screen size and text movement was not statistically significant, $F(1, 140)=0.99$, $p=.322$, $\eta_p^2 = 0.007$. Next, we performed a 2×2 between-subjects ANOVA using average backtracking distance as the dependent variable. There was no statistically significant main effect of screen size (smartphone: $M=2.54$, $SD=1.58$; tablet: $M=2.44$, $SD=1.58$; $F(1, 140)=0.14$,

$p = .706$, $\eta_p^2 = 0.001$). However, scrolling led to more distal backtracking than paging (scrolling: $M = 2.88$, $SD = 1.57$; paging $= 2.09$, $SD = 1.58$; $F(1, 140) = 8.81$, $p = .004$, $\eta_p^2 = 0.059$). The interaction between screen size and text movement was not statistically significant, $F(1, 140) = 0.38$, $p = .538$, $\eta_p^2 = 0.003$. In sum, scrolling led to less backtracking overall, yet participants who scrolled performed more distal backtracking during reading. We return to this finding in the discussion.

Finally, the results of a 2×2 between-subjects ANOVA performed to address our third research question, concerning potential effects of our experimental manipulations on motivation to perform the reading task, showed neither a statistically significant effect of screen size (smartphone: $M = 3.57$, $SD = 0.86$; tablet: $M = 3.68$, $SD = 0.86$; $F(1, 141) = 0.64$, $p = .427$, $\eta_p^2 = 0.004$), nor of text movement (scrolling: $M = 3.68$, $SD = 0.85$; paging $= 3.57$, $SD = 0.86$; $F(1, 141) = 0.59$, $p = .443$, $\eta_p^2 = 0.004$). However, the interaction between screen size and text movement was statistically significant $F(1, 141) = 6.25$, $p = .014$, $\eta_p^2 = 0.042$. This interaction is displayed in Fig. 1. In follow-up testing for simple effects, we used Holm's (1979) sequential Bonferroni correction to protect against Type 1 error. Tests of the simple effects of screen size within each level of text movement showed that there was a statistically significant difference between the smartphone ($M = 3.45$, $SD = 0.86$) and the tablet ($M = 3.92$, $SD = 0.85$) when participants were scrolling, $F(1, 141) = 5.57$, $p = .020$, $\eta_p^2 = 0.038$, but not when they were paging, $F(1, 141) = 1.42$, $p = .236$, $\eta_p^2 = 0.010$. Further, tests of the simple effects of text movement within each level of screen size showed that there was a statistically significant difference between scrolling ($M = 3.92$, $SD = 0.85$) and paging ($M = 3.45$, $SD = 0.86$) when reading on the tablet, $F(1, 141) = 5.55$, $p = .020$, $\eta_p^2 = 0.038$, but not when reading on the smartphone $F(1, 141) = 1.44$, $p = .232$, $\eta_p^2 = 0.010$. In brief, participants enjoyed reading more when scrolling than when paging on the tablet, and scrolling on the tablet resulted in a more positive reading experience than did scrolling on the smartphone.

Discussion

In this experiment, we addressed three questions that might help reading researchers understand some fundamental aspects of digital reading. These aspects, concerning the size of the screen and how readers move through the text, can be considered highly pertinent given the exponential increase in use of mobile digital devices for a variety of reading purposes (Kammerer et al., 2018; Mackey, 2020). Of note is that the study is unique, not only in investigating the effects of screen size and text movement in one and the same study, but also in investigating how these fundamental aspects of digital reading might influence integrated text understanding, processing, and motivation. Taken together, our findings indicated that text movement may matter for both text understanding and processing, while these two aspects of digital reading in concert may influence motivation to perform the reading task.

First, we found that readers who paged rather than scrolled through the text tended to display better understanding of the text. Although we, following Rosnow and Rosenthal (1989, p. 1277), believe that "God loves the .06 nearly as much as .05," it should be noted that this effect did not reach a conventional level of statistical sig-

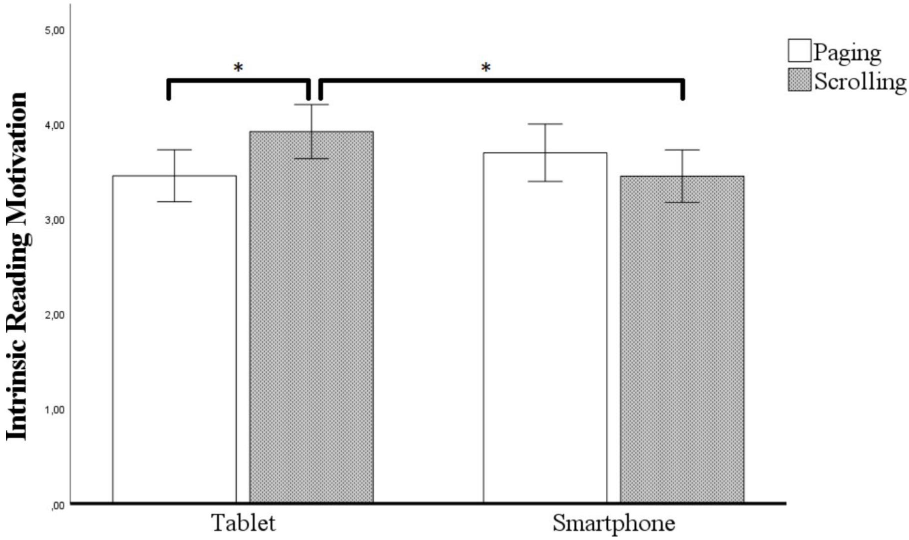

Fig. 1 *Intrinsic reading motivation for each screen size by text movement condition. Error bars represent the standard errors*

nificance. Still, it is consistent with theoretical assumptions regarding the difficulty of creating a cognitive map of the text when scrolling (Baron, 2021b; Piolat et al., 1997), as well as with some previous findings regarding detrimental effects of scrolling on written assessment tests (Piolat et al., 1997; Sanchez & Wiley, 2009). However, given the rather modest effect, further research using measures of integrated text understanding is needed to bolster this finding.

Second, we found that readers who paged rather than scrolled through the text were more likely to backtrack to previously read text during reading.This is also consistent with theoretical assumptions regarding the challenge of encoding and utilizing information about the spatial location of text when scrolling (Baron, 2021b; Piolat et al., 1997), as well as with some preliminary empirical work indicating that scrolling may lead to poorer mental representation of spatial information than paging (Piolat et al., 1997). Such backtracking to check or reread previously read text has been considered an important strategic approach when reading for understanding by reading theorists (Afflerbach & Cho, 2009; Garner, 1987; Pressley & Afflerbach, 1995; Pressley & Harris, 2006). However, in this study, the positive correlation beween backtracking and integrated text understanding was not statistically significant with a two-tailed test ($r = .15$, $p = .076$), possibly because a longer text may be needed to demonstrate this relationship.

At the same time, we found that scrolling actually led to more distal backtracking than did paging. While we cannot be sure why readers who scrolled, on average, backtracked over a longer distance, one possibility is that they were scrolling back in search for textual information that they found difficult to relocate. Another possibility is that they simply moved farther back because backward movements were more difficult to control when scrolling. However, to the extent that distal backtracking reflected an "overshooting" of the target, it did not seem to be followed by a correction forward.[2] In any case, the average distance that readers moved back in the text while reading was unrelated to their integrated text understanding in this study.

Third, we found that screen size and text movement interactively influenced readers' affective involvement in reading. Scrolling in and of itself did not reduce such task-based reading motivation; to the contrary, scrolling actually led to a more positive reading experience than paging when reading on a tablet. Possible explanations for this may be that scrolling was the habitual way of moving through digital text for these participants, and that scrolling also gave them a feeling of increased control over the reading process. However, scrolling on a smartphone was considered less motivating when reading for understanding, possibly because participants experienced more visual fatigue when scrolling on the smaller screen (Hsieh et al., 2016).

One likely reason screen size mattered less than text movement in the present study, is that the difference between the smartphone and the tablet was quite small in this regard. Still, we intentionally chose these two devices because they represent mobile devices that have become ubiquitous tools for readers across the lifespan (Baron, 2021a; Mackey, 2020). Comparing reading on these devices with reading on larger screens, such as desktop and laptop computers, with respect to integrated text understanding, text processing, and reading motivation, is a task for future researchers.

Further, although the informational text we created was longer than the texts typically used in this area of research, we consider it likely that larger effects may be obtained with even longer texts. In particular, the advantage of paging over scrolling in terms of integrated understanding may increase with longer texts because cognitive maps facilitated by paging may be more helpful with such texts. Relatedly, readers who scroll through long texts may more easily get lost in the text and have a harder time relocating information that is important for creating an integrated understanding of the text (and also be less motivated to try to do so). It follows from this that with longer texts, especially texts requiring bridging inferences across different parts of the text, the positive relationship between strategic backtracking and integrated text understanding can also be expected to increase.

In addition to increasing text length in future research, it seems pertinent to use methodologies that can provide more fine-grained analyses of readers' text processing than what the screen capture application used in this study allowed for. For example, such methodologies may include eye tracking to study how readers in the different conditions go back to check or reread specific content (see, e.g., Guo & Wang 2018; Turner et al., 2015), or concurrent thinking aloud or post-reading interviews to understand why (and why not) readers check or reread particular content (Bråten et al., 2020). Such methodologies might also provide information about instances of backtracking that are not particularly productive and help define optimal backtracking in specific reading task contexts. Of course, future research should also include other populations, varying more in prior knowledge as well as reading comprehension skills, to test the generalizability of our findings. Because we cannot exclude the possibility that participants' text movements were somewhat peculiar to the text topic

[2] When re-inspecting the recordings of the 20% of the scrollers who, on average, backtracked over the longest distance, no clear indication of correction forward was observed among these participants.

that we used in this study, informational texts on different topics should also be used in future research.

Conclusions

Although digital reading is a complex endeavor that can be characterized by an interaction of reader, text, and activity variables within a multifaceted context (Coiro, 2021), we would argue that our focus on two fundamental aspects of the digital reading context and the digital reading activity may contribute theoretically to the understanding of digital reading. In turn, understanding such basic elements of digital reading may lay the groundwork for understanding other, less fundamental aspects of digital reading (Goodwin et al., 2020). Regarding educational implications, it seems important that teachers and students become aware that the screen size and, in particular, the way readers access text when reading for understanding may influence processes and outcomes of reading. For example, students may be well adviced to use paging instead of scrolling when reading for understanding, and, when this is not an option, to try to counteract potentially negative effects of scrolling on both text processing and understanding (e.g., by means of strategic highlighting or note-taking).

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11145-022-10328-9.

Funding Open access funding provided by University of Oslo (incl Oslo University Hospital)

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