eInk versus paper: exploring the effects of medium and typographic quality on recall and reading speed

Article

Accepted Version

eInk versus paper: exploring the effects of medium and typographic quality on recall and reading speed

Abstract

This study compares the effects of reading from paper and an eInk display on recall and reading speed alongside the effects of changes in typographic quality (fluent and disfluent conditions). Both medium and typographic quality were between-subject variables resulting in four groups of participants. Each participant was timed while they read one text. They then completed a general questionnaire before answering multiple-choice questions evaluating their recall of the content they had read. Comparable reading speeds for paper and eInk were recorded and these were slower for disfluent conditions. Improved typographic quality significantly enhanced recall on eInk, whereas for paper participants who read the disfluent condition recalled more. These findings suggest that typographic quality has a significant effect on reading, which is also influenced by the medium. Although recall was better in the disfluent paper condition, some caution should be observed in translating this into recommendations that would result in more effortful reading.

Keywords: eInk, paper, recall, text layout, typography

1 Introduction

In an age where new kinds of consumer display are rapidly emerging in the marketplace and being adopted in educational contexts, a number of studies consider the suitability of particular displays and the visual presentation of materials for learning. The majority of research investigations to date, including many recent studies (e.g. Mangen *et al.*, 2013; Mangen and Kuiken, 2014; Sackstein *et al*. 2015; Köpper *et al.* 2016), have focused on backlit liquid crystal display (LCD) screens, using computers and handheld devices like the Apple iPad. Relatively few studies compare paper-based reading with reading on electronic ink (eInk) devices, such as the Amazon Kindle, Sony Reader, Barnes and Noble Nook and Kobo eReaders.

This is possibly because eInk is still a relatively new form of display technology or ‘electronic paper display’ (EPD). However, eInk is a potentially more affordable form of display in comparison to LCD devices (both in terms of upfront and running costs). eInk displays may also be less likely to replicate the detrimental effects related to reading fatigue that are associated with backlit displays (Siegenthaler *et al.*, 2011; Jabr, 2013; Flood, 2014; Köpper *et al.* 2016). In addition, from a typographic perspective, eInk merits particular investigation because it is reputed to have a display quality comparable to printed texts (Mitra, 2011; Felici, 2012). Its digital display works by utilising millions of microcapsules, all of which contain positively charged ‘white’ particles, and negatively charged ‘black’ particles. If each of these microcapsules is considered as a pixel, type and images can be rendered on a screen whilst, ostensibly, bearing a strong resemblance to the appearance of ink on paper.

Our study seeks to contribute to the emerging body of research that examines reading on eInk displays. In particular, we compare the effectiveness of reading and recalling information in expository texts on eInk and paper in relation to fluent and disfluent conditions of typographic quality. From a psychological perspective, fluency refers to the subjective experience of relative ease with which stimuli are cognitively processed. Although fluency refers to the processing of material, rather than the material itself, we use the terms fluent and disfluent conditions consistent with Diemand-Yauman *et al.* (2011).

2 Background and rationale

A substantial body of research compares learning from digital displays and paper. Reviews (e.g. Dillon, 1992; Noyes and Garland, 2003; Jabr, 2013; Köpper *et al.*, 2016) suggest that findings are sometimes inconclusive but generally show a tendency towards poorer performance in relation to reading from screen than paper (e.g. Dillon, 1992; Nielsen, 2010; Jabr, 2013; Mangen *et al.*, 2013). Studies also highlight that learners prefer reading printed textbooks to reading on screen (e.g. Shepperd *et al.*, 2008; Woody *et al.* 2010; Ackerman and Goldsmith, 2011; Gibson and Gibb, 2011) and that this preference also applies to younger generations, often referred to as 'digital natives' (see: Mangen, 2017). However, an increasing number of studies are establishing either less marked differences between learning from paper and learning from screen (e.g. Noyes and Garland, 2003; Rockinson-Szapkiw *et al.*, 2013) or reporting a significant improvement in learning from screen (e.g. Shepperd *et al.,* 2008; Siegenthaler *et al.*, 2011).

Relatively few studies specifically examine learning from eInk displays versus learning from paper. To date, a range of measures, variables and methodologies have been used so findings are not straightforward to compare.

Siegenthaler *et al.* (2011) compared reading behavior (measured through eye-tracking measurements of fixations and saccades) and reading performance (measured through reading speed and page turns) across five kinds of eInk display and one printed book. They also recorded participants' preferences for reading on each device. They concluded that reading behavior from eReaders and print is similar. However, they recorded significantly longer fixations for printed texts. This suggests that eReaders may provide better legibility because the longer fixations in the paper condition suggest that participants had greater difficulty 'extracting visual and/or linguistic information' (Siegenthaler *et al.*, 2011, p. 272).

In contrast, Mangen *et al.* (forthcoming, see also Flood, 2014; Mangen, 2017) found that participants performed better in comprehension and mental reconstruction tasks when reading a novel on paper than on a Kindle: recalling the plot and answering questions more accurately about the sequence and chronology of the narrative.

This finding could be related to particular affordances of printed and digital texts. For example, in a qualitative study of University student reading and study behavior using eReaders, Campbell, *et al.* (2013) found that the lack of spatial and kinesthetic clues – such as page numbers, headers and physical weight on eReaders – prevented cognitive maps from being created by students. Similarly, in a qualitative study of long-term academic use, Thayer *et al.* (2011) noted that students using eReaders took longer to locate information than they would when using printed resources. They also found that eReaders did not support scanning and responsive reading strategies well.

The interplay between particular genres, typographic structure and the reading strategies users are likely to engage with for specific devices is important to consider. Daniel and Willingham (2012, pp. 1581–1582) note that many current e-books (regardless of device) have a "narrative structure", whereas electronic textbooks are likely to have a "hierarchical structure". Participants in both the Siegenthaler *et al.* (2011) and Mangen *et al.* (forthcoming) studies read extracts from novels, which are likely to be read as linear texts.

In another study using narrative content, Nielson (2010) compared reading speeds between content displayed on a Kindle eInk screen, an iPad's LCD screen and traditional paper. The results showed the Kindle content was read significantly (p<.01) slower than content read on paper, whereas the iPad content was only marginally (p=.06) slower than reading from paper. Slower reading from screen compared to paper has been a fairly common finding with older technologies (Dyson and Haselgrove, 2001), although recent studies are measuring increased reading speeds for iPad compared to paper (e.g. Sackstein *et al*., 2015).

Sackstein *et al.* (2015, p. 2) suggest that studies examining the effectiveness of reading from different displays should consider reading as both a 'text-based' and 'knowledge-based' process. Accordingly, they incorporate both reading speed and comprehension as measures in their study. While Sackstein *et al.* did not establish a relationship between reading speed and comprehension, in relation to expository texts and the findings for the specific eInk studies discussed in this paper, it seems appropriate to measure both reading speed and either comprehension or recall accuracy.

An important factor to consider in relation to learning is the relative fluency/disfluency of different displays (Alter, 2013). A growing number of recent studies have compared whether the fluent and disfluent conditions influence learning (e.g. Diemand-Yauman *et al.*, 2011; Kühl *et al.*, 2014) and particular perceptual judgments (e.g. Alter and Oppenheimer, 2009; Manley, *et al.* 2015). For example, Diemand-Yauman *et al.* (2011) have considered how fluent and disfluent typographic conditions influenced participants' recall from paper. They suggest that making typography harder to read results in increased levels of cognitive engagement, which in turn enables better recall of information. The disfluency manipulation would be described by typographers as making the text less legible. In relation to perceptual judgments, Song and Schwarz (2008a) have also found that fluency can influence the assumptions learners make about how easy or difficult a task is and their associated motivations.

Many fluency studies have used changes in typeface or weight – often loosely referred to in research as "font manipulation" (Alter and Oppenheimer, 2009, p. 222) – as an indicator of fluent and disfluent conditions (e.g. Oppenheimer and Frank, 2008; Song and Schwarz, 2008a; 2008b; Diemand-Yauman *et al.*, 2011; Manley, *et al.* 2015). Changing the font is regarded as an easy way to manipulate fluency (Alter and Oppenheimer, 2009). However, it is possible that the distinctiveness of some 'disfluent' typefaces may be a confound in some of these studies (Rummer, *et al*. 2016).

In contrast, and taking on board criticisms of fluency research using typographic variables (e.g. Black, 2011; Luna, 2011), our study keeps the typeface consistent and instead manipulates a defined set of typesetting attributes (including character spacing, line length and alignment) as an indicator of fluent (legible) and disfluent (less legible) conditions. Typographic practitioners consider spacing to be one of the most essential factors that affects the legibility of how a text is typeset and argue the importance of considering the relationships between typographic attributes such as size, line length and interline spacing ('leading') in relation to legibility (e.g. Schriver, 1997; Baines and Haslam, 2005; Bringhurst, 2016).

There is also a substantial body of research that shows how typesetting attributes influence ease of reading and comprehension (e.g. Dyson, 2004, 2005; Dyson and Haselgrove, 2001; Yi *et al.,* 2011; Lonsdale, 2014). More specifically, research has found that tighter than standard character spacing reduces reading speed (Chung, 2002; Yu, Cheung, Legge and Chung, 2007). This is referred to as 'crowding' where adjacent letters jumble the appearance and make letters less visible. The number of characters per line affects the legibility of print. Lonsdale (2014) notes that there is general agreement from both a number of studies and practitioners that lines should not exceed about 70 characters per line. Research exploring line length on older screen technologies has produced mixed results but a line length of around 55 characters seems to optimize reading speed and comprehension (Dyson, 2005). The few studies which have looked at text alignment, justified versus unjustified (ragged right) text setting, have not found differences in reading speed for proficient readers. However, justified setting may introduce inconsistent spacing between words ('rivers') which may be aesthetically less pleasing (Dowding, 1966; Larson, *et al.,* 2006). These typesetting attributes might therefore be considered an appropriate means of manipulating fluency, creating different levels of text legibility.

Another factor that is regarded as a key consideration in fluency research is familiarity (Alter and Oppenheimer, 2008; Song and Schwarz, 2010). Accordingly, our study also considers whether the participants' preferences and prior experience with eInk displays may affect fluency and hence recall.

3 Methods

3.1 Objectives

The primary objectives of our study are to compare (1) the effectiveness of reading from eInk and paper in relation to reading speed and recall and (2) the effect of typographic quality on reading speed and recall for each of these mediums. In addition, our study considers participants' preferences and prior experience with eInk displays to contextualise the findings.

3.2 Research design

3.2.1 Participants

At the outset of the study, two preliminary studies with 11 participants were conducted to inform decisions about the material design. Forty volunteers participated in the main study. All participants had English as their first language to minimize the effects of variations in language familiarity (cf. Yi *et al.*, 2011).

3.2.2 Preliminary studies

The content selected for the study comprised four expository texts (i.e. suitable for textbook content) that provide an introductory overview of a topic and accompanying questions.

In the first preliminary study, a multiple-choice questionnaire covering questions on the factual content of the extract was used to establish which of these sample texts could be considered reasonably equivalent, and therefore used in the study. Extract A was discarded as it received a considerably higher percentage of correct answers than the other sample texts. Participants performed most consistently across Extracts B and D so these were adopted for the comparative tests in the main study. Extract C was adopted as the material for the user preference task in the main study. The three extracts were between 600 and 645 words in length and based on Jeremy Bentham (Everett, 1969); *The Times* newspaper (Encyclopaedia Britannica, 1998); Crystal Palace and the Great Exhibition (Hobhouse, 2002). The texts were written to ensure consistency of style and complexity.

The second preliminary study examined user preferences in order to specify an appropriate ('comfortable') type size that could be used for the eInk display materials. Participants were shown a sample of text on a Kindle in four different type sizes (sizes 2–5) selected from the eight Kindle preset sizes defined by the sample device using a normative range of sizes for reading continuous text (see Figure 1). Participants were instructed to hold the device at a comfortable reading distance and indicate their preferred sample size. The most frequently chosen option (size 4 – which can be considered reasonably equivalent to 14pt) was adopted for the eInk display materials developed for the study.

[insert Figure 1: Kindle preset sizes evaluated in the preliminary study]

3.2.3 Material design for main study

Both paper and digital materials were used for the main study. An Amazon Kindle was used for the digital displays in the study because it is the device participants were most likely to be familiar with. The Kindle Voyage, the most recent model at the time the testing was carried out, was chosen based on its screen resolution of 300dpi – equivalent in rendering quality to that of the laser printed type on the paper materials. The paper text sample was printed on a laser printer at 300dpi on standard 80gsm paper.

Both conditions were presented using standard, 'everyday' document formats that would realistically conform to participants' expectations for that particular medium. The paper samples were presented on an A4 sheet of paper – the UK standard for single-sheet documents and learning handouts. The Kindle has a six-inch screen. However, trimming the paper samples to this size for the paper-based samples could seem unconventional as this size would be much smaller than the majority of printed textbooks and educational handouts that the participants would be accustomed to. Participants were not permitted to adjust the display settings on the digital displays.

All content was typeset in Caecilia (specifically PMN Caecilia for paper and the optimized digital version of Caecilia for Kindle). This typeface is natively supported on the Kindle and so is optimised for the display device. It also renders well in print and has a good legibility due to its moderately large x-height and low contrast in stroke thickness. Using a single typeface at a normative body text size for each medium ensured that typeface and size were systematically controlled in relation to legibility.

It was considered extremely important to not simply have the exact same typographic treatments across the mediums. This would have caused both of the mediums to have sub-optimal typography and so would have been an unnecessary compromise. Suitable typography for each of the specific mediums was therefore used to create a fluent condition for each medium, which was then manipulated in reasonably equivalent ways to create the disfluent conditions. This approach has a precedent in legibility research: Poulton (1967) left the decision to a typographic designer to determine the optimal setting when deciding what size of lower case letters to compare with capitals.

The fluent settings for paper were determined first. Drawing on typographic guidance for normative or 'good' typography from Baines and Haslam (2005), fluent materials were typeset as left-aligned with no adjustments to the default character spacing. The body text was set at 9.5pt on 13pt leading. A column measure of 350pt ensured that the average number of characters per line was within the recommended average (~70 characters). The texts were edited to ensure that they fitted on a single page.

For the digital fluent condition, the text was also left-aligned with no adjustments to character spacing. Drawing on our preliminary findings, the text was typeset at size 4 with the leading at 130% (a slight adjustment of the default settings). As users would expect to scroll when reading a Kindle, we allowed for this to happen. Forcing the text to fit on a single screen would have substantially compromised legibility and/or reduced the amount of text the participants could read for the recall task. The average number of characters per line was ~45.

Materials in the disfluent condition were: justified (to create inconsistencies in word spacing), typeset with reduced ('tighter') character spacing (paper: -0.120 em; eInk: -0.162 em) and increased ('looser') interline spacing (paper: 22.75pt; eInk: 230%). For the character spacing, em spacing was used to achieve proportionate adjustments for the different typesizes and then adjusted for optical equivalence. The disfluent materials were also presented with smaller margins and therefore a substantially longer line length (paper: between 100 and 120 characters per line; eInk: approximately 80 characters per line – the maximum we could increase without substantially compromising legibility through reducing the character spacing or needing to reduce the character spacing further in the paper condition).

The samples were created in HTML and CSS, and then formatted to the ACZ3 file type. This file type is native to the Kindle and allows for slightly more control in relation to interline spacing and character spacing. This was important to ensure that as far as possible the Kindle did not automatically overwrite the specifications applied to the disfluent condition. For example, it was impossible to substantially reduce the interline spacing for the disfluent condition as the Kindle had a particular range of acceptable measures it would use.

[insert Figures 2–5]

Figures 2–5 show the fluent and disfluent conditions for eInk and paper using one of the extracts (A brief history of *The Times*). Four variations of each of the two extracts (B/D) were developed so that the combination of content (Extract B/D), device (digital/paper) and typographic quality (fluent/disfluent) could be balanced across the study. The conditions for paper and digital in both fluent and disfluent conditions were also applied to Extract C – to create an alternate set of materials which could be used to ask participants about their preferences.

3.3.4 Procedure – main study

The main study used a between-subject design such that each participant read and answered factual questions in only one condition. There were three stages. In stage 1, participants were shown and asked to read one of the sample variants (e.g. paper/eInk and fluent/disfluent) at their comfortable/natural pace. Their reading time was recorded (rather than restricted – cf. Diemand *et al.,* 2011) to provide two measures of the potential effects of disfluency and provide richer data on the effectiveness of reading. In stage 2, following Noyes and Garland (2003) who recommend a delay between reading and testing of recall, participants were asked to complete a short questionnaire. The questionnaire asked participants to indicate:

- How much previous experience they had with an eInk screen (such as a Kindle or similar device) in relation to four options (None / Very Occasionally / Fairly Frequently / Regularly)
- Their age range (16–25 / 26–35 / 36–45 / 46–55 / 56–65 / 66+) and
- Their preferences (A / B) using a paired comparison procedure which paired together each of the four variations of the Extract C so that

every possible combination was shown (six pairs). The order of presentation was randomized across the study to minimize interference from order effects. After indicating their paired preferences, participants were asked to state if they felt they had a preference for either eInk or paper.

In stage 3, participants completed a questionnaire with 10 multiple-choice factual questions based on the text they had read in stage 1. Participants were not permitted to view the original material whilst answering the questions. No time limit was specified, allowing participants to take as long as they needed to recall the content and fill out the question paper.

Results

Table 1 summarises the average reading times in seconds (stage 1) and accuracy of recall (number of correct answers in stage 3) for each condition with SDs in parentheses.

[insert Table 1]

A two-way analysis of variance of reading times found a main effect of typographic quality with faster times for fluent material ($F(1,36) = 5.44$, $p = 0.025$). This was consistent across eInk and paper (Figure 6). There is no main effect of medium ($F(1,36) = 1.89$, $p = 0.178$): reading times were similar for eInk and paper.

[insert Figure 6]

For accuracy of recall, there were no main effects but we found a significant interaction between medium and typographic quality: $F(1,36) = 38.51$, $p<0.001$. Figure 7 illustrates that recall is better for fluent material when reading an eInk display but this effect is reversed when reading from paper. Although disfluent material was read more slowly from both eInk and paper, recall was affected in different ways.

[insert Figure 7]

In stage 2, 65% of participants reported having either 'Never' (18) or 'Very Occasionally' (8) used an eInk device. As shown in Table 2, there was no clear correlation between age and prior experience with eInk – although it may be that this is related to the relatively small number of participants and some unevenness in the age groups represented.

[insert Table 2]

Table 3 compares eInk experience with recall, combining the four options on the questionnaire into two to increase the number of participants in each cell. As participants having prior experience with eInk are spread unevenly across the four conditions, it is difficult to draw any reliable conclusions concerning the relationship between experience and recall across the two mediums. However, participants who were reading the eInk fluent material seemed not to be affected by their experience (or lack thereof) with an eInk screen. Whereas the previous (reported) experience with an eInk screen of those who had to read the eInk disfluent material, may have had an influence. With harder-to-read material, lack of experience was detrimental compared with more experience. Interestingly, reported experience with eInk seemed to have a similar effect on reading from paper, although the high level of recall for the paper disfluent condition with more frequent experience with eInk is based on only one participant.

[insert Table 3]

The paired comparison data (Table 4) shows that participants selected examples in the fluent condition more frequently than those in the disfluent condition (eInk 98:26; paper 84:32). This suggests that participants prefer good typography regardless of medium. Although the difference in the ratios in the two mediums is small, eInk does have a greater disparity between fluent and disfluent. This hints at the perception of a slightly greater difference in typographic quality on eInk.

[insert Table 4]

When questioned directly on preference, 15 participants expressed a preference for eInk, 12 for paper and 13 indicated no preference. In comparison to other studies of preference (e.g. Gibson and Gibb, 2011; Shepperd *et al.*, 2008), it is perhaps surprising that eInk was preferred more times than paper, but this might reflect participant's familiarity with eInk. Table 5 compares the number of participants expressing preferences according to their experience of eInk. As might be expected, those who are more familiar with eInk are also more likely to express a preference for this medium.

[insert Table 5]

Discussion and implications

Similar to the findings from Diemand *et al.'s* (2011) study, higher recall was recorded for the disfluent paper condition. When reading from paper, the greater effort in the disfluent condition (together with a slower reading speed) may have facilitated recall. However, the same effect was not observed for eInk, with disfluent typography decreasing the accuracy of recall. Despite taking longer to read the eInk disfluent typography examples, participants were not able to recall as much as those who read the fluent condition. There are a number of possible explanations for these discrepant results for paper and eInk. For example:

- Participants may have considered the Kindle device to have more novelty and therefore shown a different level of motivation towards the task
- Different levels of confidence related to participants' relative familiarity with the device may have influenced the way they engaged with the task
- Participants may have different expectations of typographic quality for paper and eInk devices
- Digital and printed texts may have different affordances (Campbell, *et al.*, 2013; Thayer *et al.*, 2011)
- Possible better legibility of eInk fluent condition based on paired comparisons data and Siegenthaler *et al,* (2011, p. 272).

By aiming to optimize the layout for each medium, different typographic presentations were used which may have resulted in varying levels of legibility between paper and eInk (particularly where very tight character spacing may reduce legibility). However, these differences might have been greater if no account were taken of the medium. Although eInk more closely resembles paper than older technologies, print legibility results do not necessarily transfer to screen (Dyson, 2005). The reading speed results across paper and eInk suggest that there may be a similar difference between the fluent and disfluent condition in the levels of legibility on paper and eInk, taking reading speed as a measure of legibility. As participants were not restricted in their reading times (unlike in Diemand *et al.*, 2011), there is the potential for participants to trade off speed of reading and accuracy of recall.

With eInk, the reduction in the amount recalled in the disfluent condition, even when this is read slower, may be due to too much effort going into processing the text (i.e. exceeding the additional cognitive load that is supposed to help), at the expense of learning or understanding or memorizing the content. The less legible text reduced reading speed and was recalled less accurately, so there was no trade-off. This explanation of too great a load seems plausible when considering the likely interplay between recall and familiarity (Table 3). This reinforces the importance of considering issues of conventionality and familiarity when comparing paper and digital displays. It is important to ensure that the results are not distorted by a user’s relative familiarity with the device used for testing or their perceived level of confidence or motivation to engage with the materials being tested in a particular condition (cf. Alter and Oppenheimer, 2008; Song and Schwarz, 2010). The overall results for paper are consistent with a trade-off as faster reading of the fluent, more legible text, was at the expense of accurate recall. In this case, greater familiarity with paper may have encouraged less engagement.

The different pattern of results for paper and eInk has been found in a study looking at mathematics problems rather than reading continuous texts (Sidi *et al*., 2016). This study obtained results that mirror our own: i.e. they found no differences in performance between screen and print but did observe differences between the typographic conditions. In particular, Sidi *et al*. found that on screen the problems set in the less legible or less fluent typographic condition resulted in better performance. On paper, they found the reverse: a higher success rate in solving the problems when the font is legible. Our study and the Sidi *et al.* study therefore both have results in different directions for screen and paper but with the mathematical problems, the results for paper are in line with what we would predict from legibility research. Although Sidi *et al'*s study does not explain what is mediating these results, it does indicate that the characteristics of the material (e.g. the medium) can influence the results. This argues for much more subtlety in exploring the precise conditions under which legible texts may appear to disadvantage recall or comprehension.

The better recall with more fluent or legible eInk materials provides strong grounds to extend research into the impact of typographic presentation on reading and learning. This result confirms typographers' practice in prioritizing legibility and designing material to support, rather than hinder, ease of reading. Building on research that suggests a reduction in comprehension at faster reading speeds (e.g. Poulton, 1958; Dyson and Haselgrove, 2001) and other aspects of typographic presentation that can aid or hinder reading (e.g. Yi *et al*. 2011), it is important to consider how typographic presentation can contribute to slowing readers down without adding to cognitive load to the extent that this has a detrimental effect on learning. The difficulty with disfluent material also questions whether it is advisable to require readers to put more effort into deciphering text of poor typographic quality, even if recall is improved when reading from paper. Any positive effect may be offset by greater fatigue or irritation and we do not yet know whether reading for extended periods of time also shows gains for disfluent conditions. Given the higher recall for fluent eInk material, we should question the implications of recommending reducing the typographic quality of paper documents.

Engaging with learning materials requires a range of engagement strategies, particularly as instructional texts usually include a variety of different forms of text and images (continuous text, lists, tables, numerical data, graphs, illustrations, etc.). Currently, commercially available eReaders do not have colour displays. As well as restricting the display of images, this also limits the way in which structural and other visual cues are signaled to support reading. Accordingly, typographic presentation may play a particular role in helping readers determine the structure and organization of information, decide how to engage with information and also enable the ways in which they locate information. This is particularly important in relation to materiality and the absence of physical cues in comparison to printed books (Lovelace and Southall, 1983; Waller, 1986; Dillon, 1992; Van der Weel, 2011; Campbell *et al.*, 2013, Flood, 2014; Mangen and Kuiken, 2014; Mangen, 2017). As Mangen (2017) has argued, there is considerable scope for research that explores the ergonomic affordances of digital devices. Furthermore, we would add, that ways in which typographic presentation can support reading processes through navigation and structural cues should be investigated more fully. These issues are particularly important to consider further as new user interfaces and navigational styles are being developed for eReaders (see: Kozlowski, 2012).

The results show that changes between paper and eInk, combined with varying the level of typographic fluency, does affect learning-related tasks like recall. The results of this study suggest that eInk *can* be beneficial to recall particularly when paired with good typographic presentation and if users have prior experience of the medium.

Overall, the study provides some grounds to consider that eInk readers could be an appropriate alternative platform to consider for educational use, particularly when information is displayed at a good standard of typographic quality. It also raises some interesting considerations for the design and control of typographic test materials through engaging with how norms for 'good and bad' typography may translate across different mediums rather than reproducing equivalent measures that may not be appropriate for all outputs.

Acknowledgements

The research conducted in this study was conducted as part of an undergraduate dissertation at the University of Reading. The study had ethical approval from the University.

References

Ackerman, R., & Goldsmith, M. (2011). Metacognitive regulation of text learning: On screen versus on paper. *Journal of Experimental Psychology: Applied, 17*(1), 18–32.

Alter, A. L. (2013). The benefits of cognitive disfluency. *Current Directions in Psychological Science, 22*(6), 437–442.

Alter, A., & Oppenheimer, D. M. (2008). Easy on the mind, easy on the wallet: The roles of familiarity and processing fluency in valuation judgments. *Psychonomic Bulletin & Review, 15*(5), 985–990.

Alter, A. L., & Oppenheimer, D. M. (2009). Uniting the tribes of fluency to form a metacognitive nation. *Personality and Social Psychology Review, 13*(3), 219–235.

Baines, P., & Haslam, A. (2005). *Type & typography* (Second ed.). London: Laurence King Publishing.

Black, A. (2011). Good fonts, bad fonts. *Brain attic*. Published online at: http://brain-attic.blogspot.co.uk/2011/01/good-fonts-bad-fonts.html [Accessed 9 December 2016].

Bringhurst, R. (2016). *The elements of typographic style*. Seattle: Hartley & Marks.

Campbell, A., Callaghan, G., McGarvie, D., & Hynd, M. (2013). Do students study and learn differently using e-readers? A cross-discipline research investigation into the pedagogical implications of using e-readers to study university level text. Paper presented at the *QAA Enhancement Themes International Conference on Enhancement and Innovation in Higher Education*, June 2013. Scotland: Open University.

Chung, S. T. L. (2002). The effect of letter spacing on reading speed in central and peripheral vision. *Investigative Ophthalmology & Visual Science, 43*(4), 1270–1276.

Daniel, D. B., & Willingham, D. T. (2012). Electronic textbooks: Why the rush? *Science, 335*(6076), 1569–1570.

Diemand-Yauman, C., Oppenheimer, D. M., & Vaughan, E. B. (2011). Fortune favors the bold (and the italicized): Effects of disfluency on educational outcomes. *Cognition, 118*(1), 111–115.

Dillon, A. (1992). Reading from paper versus screens: A critical review of the empirical literature. *Ergonomics, 35*(10), 1297–1326.

Dowding, G. (1966). *Finer points in the spacing and arrangement of type*. London: Wace.

Dyson, M. C. (2004). How physical text layout affects reading from screen. *Behaviour & Information Technology, 23*(6), 377–393.

Dyson, M. C. (2005). How do we read text on screen? In H. van Oostendorp, L. Breure & A. Dillon (Eds.), *Creation, use, and deployment of digital information* (pp. 279–306). Mahwah, NJ: Lawrence Erlbaum Associates.

Dyson, M. C., & Haselgrove, M. (2001). The influence of reading speed and line length on the effectiveness of reading from screen. *International Journal of Human-Computer Studies, 54*, 585–612.

Encyclopaedia Britannica. (1998) *The Times*: British newspaper. Published online at https://www.britannica.com/topic/The-Times [Accessed: 1 June 2018].

Everett, C. W. (1969). *Jeremy Bentham*: Littlehampton Book Services.

Felici, J. (2012). *The State of E-book Typography*. Creative Pro. Published online at: www.creativepro.com/article/state-e-book-typography [Accessed: 15 April 2015].

Flood, A. (2014). Readers absorb less on Kindles than on paper, study finds. *The Guardian*. Published online at: https://www.theguardian.com/books/2014/aug/19/readers-absorb-less-kindles-paper-study-plot-ereader-digitisation, 19 August 2014 [Accessed: 2 August 2016].

Gibson, C., & Gibb, F. An evaluation of second-generation ebook readers. *Electronic Library, 29*(3), 303–319.

Hobhouse, H. (2002). *The Crystal Palace and the Great Exhibition: Art, science, and productive industry: A history of the royal commission for the exhibition of 1851*. Continuum International Publishing Group.

Jabr, F. (2013). The reading brain in the digital age: The science of paper versus screens. *Scientific American*. Published online at: www.scientificamerican.com/article/reading-paper-screens [Accessed: 14 April 2015].

Köpper, M., Mayr, S., & Buchner, A. (2016). Reading from computer screen versus reading from paper: Does it still make a difference? *Ergonomics, 59*(5), 615–632.

Kozlowski, M. (2012). *eBook and Digital Publishing News*. Good E-Reader. Published online at: goodereader.com/blog/tablet- slates/kaist-itc-demonstrates-a-new-smart-e-book-interface [Accessed: 15 April 2015].

Kühl, T., Eitel, A., Damnik, G., & Körndle, H. (2014). The impact of disfluency, pacing, and students' need for cognition on learning with multimedia. *Computers in Human Behavior, 35*, 189–198.

Larson K., Hazlett R.L., Chaparro B.S., Picard R.W. (2007). Measuring the Aesthetics of Reading. In: Bryan-Kinns N., Blanford A., Curzon P., Nigay L. (eds) *People and Computers XX — Engage*. Springer, London, 41–56.

Lonsdale, M. d. S. (2014). Typographic features of text: Outcomes from research and practice. *Visible Language, 48*(3), 29–67.

Lovelace, E. A., & Southall, S. D. (1983). Memory for words in prose and their locations on the page. *Memory and Cognition, 11*(5), 429–434.

Luna, P. (2011). Pretty ugly. *Luna's café*. 1 November 2016. Published online at: http://www.lunascafe.org/2011/01/pretty-ugly.html [Accessed: 9 December 2016].

Mangen, A. (2017). Textual reading on paper and screens: Implications for design. In A. Black, P. Luna, O. Lund & S. Walker (Eds.), *Information design: Research and practice* (pp. 275–289). London: Routledge.

Mangen, A., & Kuiken, D. (2014). Lost in the iPad: Narrative engagement on paper and tablet. *Scientific Study of Literature, 4*(2), 150–177.

Mangen, A., Velay, J-L, Robinet, P. & Olivier, G. (forthcoming). Where in the book and when in the story? Comparing comprehension when reading a mystery story in print and on Kindle.

Mangen, A., Walgermo, B. R., & Brønnick, K. (2013). Reading linear texts on paper versus computer screen: Effects on reading comprehension. *International Journal of Educational Research, 58*, 61–68.

Manley, A. J., Lavender, T., & Smith, D. M. (2015). Processing fluency effects: Can the content and presentation of participant information sheets influence recruitment and participation for an antenatal intervention? *Patient Education and Counseling, 98*(3), 391–394.

Mitra, S. (2011). *New Kindle* Heats *Up E-Reader Market*. Published online at: www.sramanamitra.com/2011/10/30/new-kindle- heats-up-e-reader-market [Accessed: 14 April 2015].

Nielsen, J. (2010). iPad and Kindle Reading Speeds. *Nielsen Norman Group*. Published online at: www.nngroup.com/ articles/ipad-and-kindle-reading-speeds [Accessed: 15 April 2015].

Noyes, J. M., & Garland, K. J. (2003). VDT versus paper-based text: Reply to Mayes, Sims and Koonce. *International Journal of Industrial Ergonomics, 31*(6), 411–423.

Oppenheimer, D. M., & Frank, M. C. (2008). A rose in any other font would not smell as sweet: Effects of perceptual fluency on categorization. *Cognition, 106*(3), 1178–1194.

Poulton, E. C. (1958). Time for reading and memory. *British Journal of Psychology, 49*(3), 230–245.

Poulton, E. C. (1967). Searching for newspapers headlines printed in capitals or lower-case letters. *Journal of Applied Psychology, 51*(5), 417–425.

Rockinson-Szapkiw, A. J., Courduff, J., Carter, K., & Bennett, D. (2013). Electronic versus traditional print textbooks: A comparison study on the influence of university students' learning. *Computers & Education, 63*, 259–266.

Rummer, R., Schweppe, J., & Schwede, A. (2016). Fortune is fickle: Null-effects of disfluency on learning outcomes. *Metacognition and Learning, 11*(1), 57–70.

Sackstein, S., Spark, L., & Jenkins, A. (2015). Are e-books effective tools for learning? Reading speed and comprehension: IPad®[i] vs. Paper. *South African Journal of Education, 35*(4), 1–14.

Schriver, K. A. (1997). *Dynamics in document design: Creating text for readers.* New York: Wiley.

Shepperd, J. A., Grace, J. L., & Koch, E. J. (2008). Evaluating the electronic textbook: Is it time to dispense with the paper text.? *Teaching of Psychology, 35*(1), 2–5.

Sidi, Y., Ophir, Y., & Ackerman, R. (2016). Generalizing screen inferiority – does the medium, screen versus paper, affect performance even with brief tasks? *Metacognition and Learning, 11*(1), 15–33.

Siegenthaler, E., Wurtz, P., Bergamin, P., & Groner, R. (2011). Comparing reading processes on e-ink displays and print. *Displays, 32*(5), 268–273.

Song, H., & Schwarz, N. (2008a). If it's hard to read, it's hard to do: Processing fluency affects effort prediction and motivation. *Psychological Science, 19*(10), 986–988.

Song, H. J., & Schwarz, N. (2008b). Fluency and the detection of misleading questions: Low processing fluency attenuates the Moses illusion. *Social Cognition, 26*(6), 791–799.

Song, H., & Schwarz, N. (2010). If it's easy to read, it's easy to do, pretty, good, and true. *The Psychologist, 23*(2), 108–111.

Thayer, A., Lee, C., Hwang, L., Sales, H., Sen, P., & Dalal, N. (2011). The imposition and superimposition of digital reading technology. *CHI '11 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2917–2926).

Van der Weel, A. (2011). *Changing our textual minds: Towards a digital order of knowledge.* Manchester: Manchester University Press.

Waller, R. (1986). What electronic books will have to be better than. *Information Design Journal, 5*(1), 72–75.

Woody, W. D., Daniel, D. B., & Baker, C. A. (2010). E-books or textbooks: Students prefer textbooks. *Computers & Education, 55*(3), 945–948.

Yi, W., Park, E. and Cho, K. (2011). e-book readability, comprehensibility and satisfaction. *Proceedings of the 5th International Conference on Ubiquitous Information Management and Communication – ICUIMC ’11*. Published online at: doi:10.1145/1968613.1968660.

Yu, D., Cheung, S.-H., Legge, G. E., & Chung, S. T. L. (2007). Effect of letter spacing on visual span and reading speed. *Journal of Vision, 7*(2), 1–10.

Table 1: results						
	Fluent		**Disfluent**		**Fluent + disfluent**	
	Reading times (secs)	**Accuracy of recall**	**Reading times**	**Accuracy of recall**	**Reading times**	**Accuracy of recall**
eInk	192.40 (23.76)	7.30 (0.67)	212.80 (25.46)	4.70 (1.95)	202.60 (26.15)	6.00 (1.95)
print	180.30 (27.98)	3.90 (1.29)	200.80 (32.82)	6.80 (1.40)	190.55 (31.49)	5.35 (1.98)
eInk + print	186.35 (26.02)	5.6 (2.01)	206.8 (29.24)	5.75 (1.97)		

Table 2: Age and familiarity with eInk						
Familiarity	**Age**					
	18–25	**26–35**	**36–45**	**46–55**	**56–66**	**66+**
None	10	1	0	4	1	2
Very occasionally	5	0	0	3	0	0
Fairly frequently	3	3	0	1	1	0
Regularly	1	2	0	3	0	0
Total number of participants	**19**	**6**	**0**	**11**	**2**	**2**

Table 3: average number of correct answers (recall) according to reported previous experience with eInk screen				
	eink	eink	paper	paper
	fluent	disfluent	fluent	Disfluent
Fairly frequently + regularly	7.20 N=5	5.50 N=4	3.00 N=4	8.00 N=1
None + very occasionally	7.40 N=5	4.17 N=6	4.50 N=6	6.67 N=9

Table 4: Paired comparisons			
eInk fluent	eInk disfluent	Paper fluent	Paper disfluent
37	3	–	–
24	–	16	–
–	7	33	
37	–	–	3
–	16	–	24
–	–	35	5
Total 98	Total 26	Total 84	Total 32

Table 5: preferences according to reported previous experience			
	eInk preferred	paper preferred	no preference
Fairly frequently + regularly	8	3	3
None + very occasionally	7	9	10

Figure 1

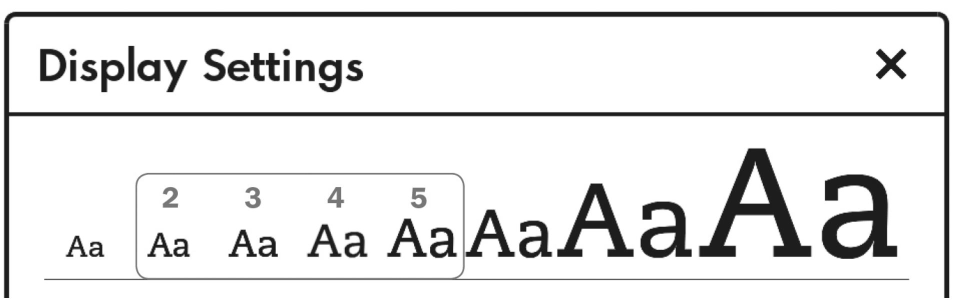

Figure 2

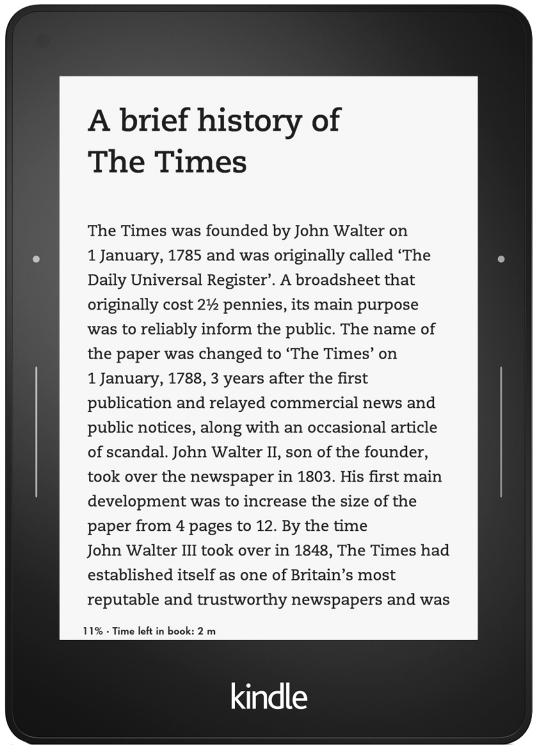
A brief history of
The Times
The Times was founded by John Walter on
1 January, 1785 and was originally called 'The
Daily Universal Register'. A broadsheet that
originally cost 2½ pennies, its main purpose
was to reliably inform the public. The name of
the paper was changed to 'The Times' on
1 January, 1788, 3 years after the first
publication and relayed commercial news and
public notices, along with an occasional article
of scandal. John Walter II, son of the founder,
took over the newspaper in 1803. His first main
development was to increase the size of the
paper from 4 pages to 12. By the time
John Walter III took over in 1848, The Times had
established itself as one of Britain's most
reputable and trustworthy newspapers and was
11% · Time left in book: 2 m
kindle

Figure 3

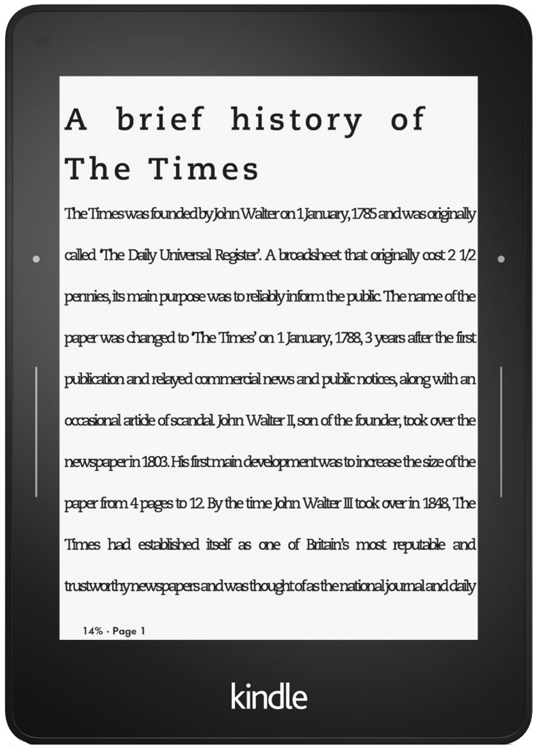
A brief history of The Times
The Times was founded by John Walter on 1 January, 1785 and was originally called 'The Daily Universal Register'. A broadsheet that originally cost 2 1/2 pennies, its main purpose was to reliably inform the public. The name of the paper was changed to 'The Times' on 1 January, 1788, 3 years after the first publication and relayed commercial news and public notices, along with an occasional article of scandal. John Walter II, son of the founder, took over the newspaper in 1803. His first main development was to increase the size of the paper from 4 pages to 12. By the time John Walter III took over in 1848, The Times had established itself as one of Britain's most reputable and trustworthy newspapers and was thought of as the national journal and daily
14% · Page 1
kindle

Figure 4

A brief history of The Times

The Times was founded by John Walter on 1 January, 1785 and was originally called 'The Daily Universal Register'. A broadsheet that originally cost 2½ pennies, its main purpose was to reliably inform the public.
The name of the paper was changed to 'The Times' on 1 January, 1788, 3 years after the first publication and relayed commercial news and public notices, along with an occasional article of scandal. John Walter II, son of the founder, took over the newspaper in 1803. His first main development was to increase the size of the paper from 4 pages to 12. By the time John Walter III took over in 1848, The Times had established itself as one of Britain's most reputable and trustworthy newspapers and was thought of as the national journal and daily historical record.

Under the watchful eye of The Times first truly great liberal editor, Thomas Barnes, who was active between 1817 and 1841, The Times developed into a strong independent newspaper popularly described as 'The Thunderer'. By the mid–1800s, the paper had grown to become an extremely influential medium for British public opinion, which dramatically increased circulation: from 5,000 copies in 1815, to 40,000 in 1850. It built a reputation by maintaining rigorous standards of reporting and writing and made great efforts to ensure meticulous accuracy. It slowly began to get ruled by tradition and ensured throughout the years that this tradition remained. Despite the fact its editorial views were very independent, articulate and strong, it also managed to be seen as the embodiment of the British establishment. It continually remained at the forefront of technology, including new methods of printing, such as the Koenig Cylinder Press. John Delane took over as editor in 1841, and hired the world's first war correspondent. The main purpose of this was to follow and document the Crimean War. The Times became so established and reliable both internally within Britain and abroad that even the British government was forced to find information indirectly from The Times, such as learning of the Russian peace proposals.

The Times took a dramatic turn for the worse in the late 19th century, after a period of overspending and the inadvertent publication of an article which wrongly accused Irish national hero Charles Stewart Parnell of forgery. This brought the company's finances, reputation and circulation to an all time low. In a bid for recovery, The Times entered into an advertising agreement with the publishers of the Britannica Encyclopædia and to sell the 9th and 10th editions. This helped, although it wasn't until the far more sensationalist Lord Alfred Harmsworth purchased the paper that The Times became more financially stable. This came at a cost, as with this new kind of journalism, accuracy was lost at the expense of excitement and public interest, and so slowly the reputation of the paper continued to deteriorate. The deterioration continued until Harmsworth's death in 1922.

Sir William Haley, who was at the time the Director General of the BBC became the new editor from 1952 to 1967. This marked a turning point for The Times and it began to recover its reputation following its swift decline. Design decisions, as well as editorial changes, were introduced to make the paper appear more visually exciting and more interesting, whilst still ensuring the traditional values. Content began to take precedence over advertising on the front page from 1966 until 1978, when disputes between management and labour over many issues, including the implementation of modern typesetting and printing techniques, led to the suspension of the paper for almost a year. Nevertheless, when the paper returned, its reputation survived and the Times continued to thrive.

Figure 5

A brief history of The Times

The Times was founded by John Walter on 1 January, 1785 and was originally called 'The Daily Universal Register'. A broadsheet that originally cost 2 1/2 pennies, its main purpose was to reliably inform the public. The name of the paper was changed to 'The Times' on 1 January, 1788, 3 years after the first publication and relayed commercial news and public notices, along with an occasional article of scandal. John Walter II, son of the founder, took over the newspaper in 1803. His first main development was to increase the size of the paper from 4 pages to 12. By the time John Walter III took over in 1848, The Times had established itself as one of Britain's most reputable and trustworthy newspapers and was thought of as the national journal and daily historical record.

Under the watchful eye of The Times first truly great liberal editor, Thomas Barnes, who was active between 1817 and 1841, The Times developed into a strong independent newspaper popularly described as 'The Thunderer'. By the mid–1800s, the paper had grown to become an extremely influential medium for British public opinion, which dramatically increased circulation: from 5,000 copies in 1815, to 40,000 in 1850. It built a reputation by maintaining rigorous standards of reporting and writing and made great efforts to ensure meticulous accuracy. It slowly began to get ruled by tradition and ensured throughout the years that this tradition remained. Despite the fact its editorial views were very independent, articulate and strong, it also managed to be seen as the embodiment of the British establishment. It continually remained at the forefront of technology, including new methods of printing, such as the Koenig Cylinder Press. John Delane took over as editor in 1841, and hired the world's first war correspondent. The main purpose of this was to follow and document the Crimean War. The Times became so established and reliable both internally within Britain and abroad that even the British government was forced to find information indirectly from The Times, such as learning of the Russian peace proposals. The Times took a dramatic turn for the worse in the late 19th century, after a period of overspending and the inadvertent publication of an article which wrongly accused Irish national hero Charles Stewart Parnell of forgery. This brought the company's finances, reputation and circulation to an all time low. In a bid for recovery, The Times entered into an advertising agreement with the publishers of the Britannica Encyclopaedia and to sell the 9th and 10th editions. This helped, although it wasn't until the far more sensationalist Lord Alfred Harmsworth purchased the paper that The Times became more financially stable. This came at a cost, as with this new kind of journalism, accuracy was lost at the expense of excitement and public interest, and so slowly the reputation of the paper continued to deteriorate. The deterioration continued until Harmsworth's death in 1922.

Sir William Haley, who was at the time the Director General of the BBC became the new editor from 1952 to 1967. This marked a turning point for The Times and it began to recover its reputation following its swift decline. Design decisions, as well as editorial changes, were introduced to make the paper appear more visually exciting and more interesting, whilst still ensuring the traditional values. Content began to take precedence over advertising on the front page from 1966 until 1978, when disputes between management and labour over many issues, including the implementation of modern typesetting and printing techniques, led to the suspension of the paper for almost a year. Nevertheless, when the paper returned, its reputation survived and the Times continued to thrive.

Figure 6

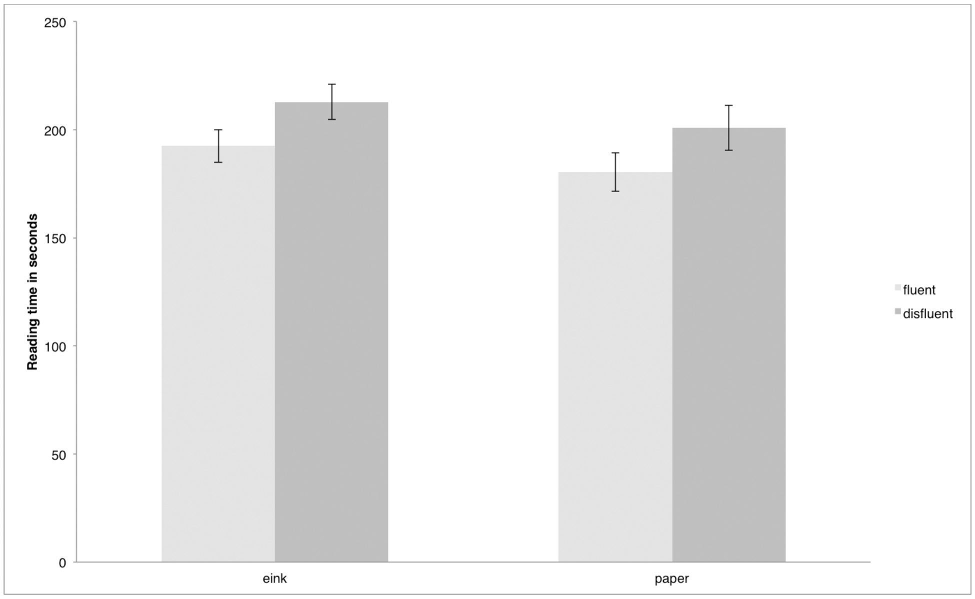

Figure 7