



Reading linear texts on paper versus computer screen: Effects on reading comprehension

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ABSTRACT

Objective: To explore effects of the technological interface on reading comprehension in a Norwegian school context.

Participants: 72 tenth graders from two different primary schools in Norway.

Method: The students were randomized into two groups, where the first group read two texts (1400–2000 words) in print, and the other group read the same texts as PDF on a computer screen. In addition pretests in reading comprehension, word reading and vocabulary were administered. A multiple regression analysis was carried out to investigate to what extent reading modality would influence the students' scores on the reading comprehension measure.

Conclusion: Main findings show that students who read texts in print scored significantly better on the reading comprehension test than students who read the texts digitally. Implications of these findings for policymaking and test development are discussed.

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1. Introduction

There is an ongoing transition of reading from print to screen and the book is challenged by an increasing number of digital reading devices (computers and laptops, e-books, tablet devices, smart phones). The paradigm of reading, in particular for young people, is increasingly screen-based rather than paperbound. The theoretical and pedagogical implications of the ongoing digitization for reading and reading comprehension are complex and multifaceted, and a number of fundamental research questions remain at best partially addressed: how and to what extent might comprehension of linear, narrative and non-narrative texts differ when texts are displayed on a screen as compared to being printed on paper? Does it impact students' reading comprehension and learning to read geography, science and history texts as PDFs on a computer screen instead of in a print text book? In the Norwegian school system, these issues have become highly relevant as texts are increasingly distributed as PDF files and there is a shift toward using computer-presented PDFs in realistic test situations. To what extent does such a shift affect reading comprehension? This is the topic of the present study.

There exists a large body of research on the impact and effect of different aspects of digital textuality on reading comprehension. Many studies have been addressing the impact of hypertext structure on cognitive aspects of reading and comprehension. A recent review (DeStefano & LeFevre, 2007) concluded that hypertext structure tends to increase cognitive demands of decision making and visual processing and this additional cognitive load, in turn, impairs reading comprehension performance.

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However, not all digital texts are hypertexts. Hence, digital reading does not necessarily entail increased cognitive load caused by hypertext features. Compared with the amount of research on hypertext reading, the number of studies specifically addressing the potential differences between sequential and continuous reading of linear, narrative and non-narrative texts in print and on screen is small. Moreover, as observed by Andrew Dillon (1992) as well as by Graesser, Millis, and Zwaan (1997), there is a lack of empirical studies using naturalistic texts (narrative or non-narrative) which are longer than one or a few paragraphs. Additionally, several early studies assessed reading comprehension of print and computer-mediated texts with the intention of clarifying factors of computer-presentation of text which facilitate reading comprehension (e.g., definitions of key concepts; access to background information; technical features of layout and organization) (Reinking, 1988). One study (Rice, 1994) employed two measures to examine reading comprehension of short texts (142 words): a text recall measure and a highlighting task (in order to examine reading comprehension in a so-called “interactive mode”). The findings revealed no significant effect for presentation mode (screen or paper) on the recall measure. However, on the interactive measure, a significant main effect was found for presentation mode, with paper being significantly better than computer. The authors concluded that reading comprehension constructs appears to be the same between computer presentation and paper presentation of text, but when readers engage in a highlighting task, a significant effect is found for presentation medium (paper over computer).

In a more recent study (Wästlund, Reinikka, Norlander, & Archer, 2005), two experiments compared production (writing) and comprehension performance. In the first experiment, subjects read 10-page PDF documents containing five different texts each averaging 1000 words and followed by a multiple-choice test (more specifically, the READ-test designed to measure Swedish language reading comprehension). In the second experiment, subjects read short newspaper articles with a mean length of 70 words and were instructed to create an appropriate headline to each article (requiring rapid acquisition and comprehension of verbal material). Time allocated to reading was limited in both experiments. The authors found that in both experiments, performance in the computer condition was inferior to that of the paper presentation condition, both in terms of writing and reading comprehension. Additionally, subjects in the computer reading condition reported higher levels of experienced stress and tiredness than those reading from paper. Hence, Wästlund et al. concluded that reading and working with a computer results in a higher cognitive workload compared with paper (Wästlund et al., 2005; cf. also Wästlund, 2007).

Noyes and Garland have conducted a number of studies on the effect of presentation medium on comprehension performance in the field of ergonomics, human factors, and design (Garland & Noyes, 2004; Noyes & Garland, 2003, 2008). In one study (Noyes & Garland, 2003), they compared reading on a computer (VDT [video display terminal]) versus reading on paper while measuring study and reading times, factual recall and comprehension. The texts were adapted from an introductory economics course, comprised of 22 print pages and were matched for size, color and resolution across media. In order to more accurately measure the potential impact of presentation medium on learning performance, Noyes and Garland employed an additional measure in conjunction with comprehension scores, namely memory awareness ratings in terms of the Remember–Know learning paradigm. Indicating the manner in which the material is cognitively processed, assimilated and retrieved, memory awareness measures are used by psychologists to gauge the nature and quality of recall and, by implication, learning. Originally developed by Tulving (1985), the Remember–Know paradigm describes two main types of retrieval response, Remember versus Know. Knowledge which is Remembered is typically recollected in close association with related information pertaining to the learning episode. By contrast, knowledge which is Known is recalled, retrieved and applied without any such additional contextual associations and “thus, is information which is simply based on a certain sense of just knowing or familiarity [. . .]” (Noyes & Garland, 2003, p. 415) One important implication is that the Remember type of memory is thus more vulnerable to fading with time, than knowledge which is Known. By implication, it is assumed that knowledge which is Known is indicative of better learning (Conway, Gardiner, Perfect, Anderson, & Cohen, 1997; Herbert & Burt, 2001). In their experiment, Noyes and Garland (2003) found no differences between the two media (paper versus VDT) in terms of study and reading times, and number of correct answers. On the qualitative comprehension measures, however, there was an effect of presentation medium, with Remember frequencies being almost twice that of Know frequencies in the computer group, while Remember and Know response levels were similar in the Paper group. Noyes and Garland conclude that “characteristics of the computer screen (refresh rate, high levels of contrast and fluctuating luminance) interfere with cognitive processing for long-term memory” (2003, p. 420). These findings were replicated in a later study (Garland & Noyes, 2004), which showed lower Know levels in the computer condition compared with the paper condition. This implies that knowledge transition from the episodic memory (indexed by Remember responses) to the semantic memory (indexed by Know responses) appears to be dependent on the nature of presentation format (screen versus paper): “The knowledge transition was much more rapid for those learning from printed material, suggesting less interference to the process of schematization, and consequently more readily applied knowledge. Hence, this suggests there still appears to be a benefit attached to learning from paper-based rather than computer-based materials” (Garland & Noyes, 2004, p. 51). One important implication of these findings is that knowledge seems to be better assimilated and more readily retrieved when presented in paper format.

In one of the few studies assessing children’s reading performance on paper and screen (Kerr & Symons, 2006), the researchers examined whether children’s reading rate, comprehension, and recall were affected by computer presentation. Sixty-fifth grade students read two expository texts, one in print and one on a computer screen. The texts were 372 and 411 words long and hence required a limited amount of scrolling in the computer condition. Recall and comprehension measures entailed using lists of generated questions that tested recall of specific information from the texts as well as the ability to

generate the required inferences for appropriate comprehension. The results indicate that children read text more slowly on computers than on paper, and they recalled more of the information that they had read from the computer than from paper. However, the children were more efficient at comprehending the texts when reading from paper (comprehension efficiency calculated as a product of accuracy and reading rate). These findings suggest that “while children, if given enough time, may be able to comprehend equal amounts of information from paper and computer, when reading time is accounted for, children are comprehending less efficiently when reading from computer” (Kerr & Symons, 2006, pp. 13–14).

The potential effect of presentation medium on reading comprehension is also an issue for essay marking and annotation. In several countries there is currently a shift toward assessors marking digitally scanned copies on screen rather than the original paper copies traditionally used (Coniam, 2011; Johnson, Hopkin, & Shiell, 2011; Johnson & Nádas, 2009; Johnson, Nádas, & Bell, 2010). With extended essays in particular, the potential effect of the presentation medium on reading comprehension becomes an issue. The findings of one recent study addressing this issue (Johnson & Nádas, 2009), suggest that examiners had a weaker recall of essay quality on screen and had greater difficulty recollecting the location of details in these texts. Interview data support the suggestion that the examiners’ comprehension was more challenged when reading from screen than from paper (Johnson & Nádas, 2009).

In the present study, we strived for a more natural setting than that of a laboratory, employing classrooms in a test-like situation, hence extending previous research within this field with regard to ecological validity. The stimulus material consisted of two authentic texts that are both quite representative for their respective genres (i.e., narrative and expository). As we wanted the texts to be as close to identical as possible across presentation media, we had subjects read PDF versions on computer screens and paper, respectively. We hypothesized (1) that we would find, as in previous research, better reading comprehension when texts were read on paper, and (2) that the expository text would be more affected by reading modality than the narrative, due to the possible higher cognitive load introduced by the topic of the text.

An additional motivation for this study is that the scoring system employed is planned implemented in national assessments of reading in Norway. Hence, the study reported here also has direct implications for policymaking and test development.

2. Methods

2.1. Participants

Participants ($n = 72$; 43% females) were 10th grade students in two urban primary schools in Norway. Age was not systematically assessed, as all subjects were selected to be 15 or 16 years old as shown by class/school records. Thus, we know that the range was 15–16 and hence mean and median age was >15 and <16 . The sample is middle-class Caucasian, and hence homogenous with respect to socio-economic status and ethnicity.

2.2. Material and procedure

All measures were administered in the students’ respective classrooms and carried out by the authors and a research assistant. All students received pretests in reading comprehension, word reading and vocabulary.

2.2.1. Reading-comprehension measures

The participants received a reading-comprehension pretest consisting of one narrative and one expository text. Each text was followed by multiple choice (MC) items, and in addition a few short-answer constructed response (CR) questions (12–20).

One of these texts was designed at the National Centre for Reading Education and Research (The Reading Centre) in Norway and one text was an example text from OECD Programme for International Student Assessment (PISA) – a study to assess reading comprehension/literacy among 15-year-olds (Lie, Kjærnsli, Roe, & Turmo, 2001). The texts contained 1400–1600 words and included graphical and/or pictorial illustrations. The format and number of pages for each text were identical for on-screen and on-paper presentation. For all texts used in the present study the questions were designed to capture five different aspects of reading comprehension in line with the five comprehension processes used for item development in PISA. As in PISA, it was not possible to report each of the five aspects as separate subscales, therefore these five aspects were organized into three broader aspect categories: (1) access and retrieve, (2) integrate and interpret and (3) reflect and evaluate.

The students were allowed to look back at the text passages while answering the questions. Those who read digitally were able to scroll up and down the pages, and change between the PDF and answering questions.

2.2.2. Word reading

Students’ word reading abilities were measured using a word-chain test (<http://www.udir.no/Vurdering/Kartlegging-videregaende-opplaring/Lesing/>). This is a screening test where the participants are instructed to segment letters into their constituent words. Four words are combined in each word chain. The words are nouns, verbs, adjectives, adverbs, prepositions or numerals, and they vary in length from two to six letters. Each chain consists of words which are semantically unrelated (Anglicized example: housecarseafree). There are 74 word chains in the test, and the students have a time limit of

4 min to solve as many word-chains as possible. The reliability coefficient, Cronbach's alpha, was .86 in the standardization sample (Høien & Tønnesen, 2008).

2.2.3. Vocabulary

A traditional single-word-item semantic vocabulary pretest was used to obtain information regarding students' vocabulary (Buch-Iversen, 2010). The test consisted of 24 items. Each item contained one stem-word, and the students' task was to find the stem-words synonym among two distractors. Anglicized example: sword (stem) – bayonet – lance – sabre (key).

2.2.4. Main survey

Four weeks after the pretests were carried out, the students received another reading comprehension test consisting of one narrative and expository text. This test was also designed at The Reading Centre and constructed to capture the three aspect categories of reading comprehension used for item development in PISA. This time the reading-comprehension-test was organized as a randomized controlled experiment, and the learners in each class were randomized into two groups:

- Group 1 read the texts digitally/on screen.
- Group 2 read the texts on paper.

Both groups answered questions digitally/on screen. The time limit was 1 h. All students who took part in the experiment submitted their tests within this time limit.

The reading comprehension measures used in the main study were designed at The Reading Centre. With respect to reliability, all texts used in this study, both for pretesting and in the main survey had Cronbach's alpha $>.75$.

2.3. Instruments

The computer displays were 15 "LCD monitors operating at 60 Hz, at a resolution of 1280×1024 pixels. The computers were familiar to the subjects as it was the computers the students used in school on a daily basis. The digitally presented texts were presented as PDF-files, read using Adobe Reader version 9.4 for Windows XP. For group 2 the same texts were printed on A-4 size paper ($210 \text{ mm} \times 297 \text{ mm}$). The font was black, 14 point, Times new roman, at 100% scale. The students had Internet access, but were not allowed to switch to any other Internet-based activities while taking the test.

2.4. Data analysis

Normally distributed variable are presented as means and standard deviations for descriptive purposes. A sequential regression analysis was used to investigate differences between the print reading condition and the screen reading condition. To control for vocabulary, word reading skill and reading comprehension, the variables were entered in the first block of the analysis, followed by sex and a binary dummy variable representing experimental condition (paper versus on-screen reading). The regression analysis was checked for multicollinearity using the approach recommended by Belsley, Kuh, and Welsch (1980), and for leverage, heteroscedacity, and normality of residuals.

To investigate possible relative differences between effects of on-screen reading versus paper reading for the narrative versus expository text, we computed standardized scores for reading comprehension for both texts in order to rescale the variables into directly comparable units. For each subject, the difference score between the standardized comprehension score for the expository text and the narrative text, was computed. Finally, differences in mean pretest-scores (vocabulary and word-chain) and differences of mean difference scores for reading on-screen versus paper were analyzed using a sequential regression analysis. All analyses were conducted using SPSS version 18.03.

3. Results

A *t*-test for individual samples revealed that the two groups did not differ significantly from each other on the pretests (vocabulary: $t(70) = -.41$, $p = .88$, word-chain: $t(70) = .25$, $p = .80$, both *t*-tests two-tailed) indicating that the students who read the text on paper and on screen were similar regarding reading comprehension/ability.

Table 1 lists mean scores, standard deviations and effect sizes on the pretests for the two groups of participants. Cohen's *d* effect sizes are considered as small ($d \leq .3$), medium ($d \approx .5$) or large ($d \geq .8$) by convention (Cohen, 1988).

Table 2 shows the results of the sequential regression analyses. The model was considerably improved by each step of the analysis, as shown by the significant R^2 changes. When adding reading modality as a predictor in block three, the explained variance increased by 4%, $p = .025$. The total explained variance was 42% in step three with all predictors included in the equation.

In the final model, word-reading ability ($\beta = .144$, $p = .043$) and vocabulary ($\beta = .551$, $p = .009$) were both positive predictors of reading-comprehension scores. After controlling for the variance associated with the variables vocabulary, word-reading, reading comprehension and gender, the reading modality variable accounted for additional variance. Reading

Table 1
Scores on the pretests for the two groups of students who participated in the experiment.

	Reading modality	N	Mean	SD	Effect size ^a
Reading comprehension	Paper	25	19.5	6.3	-.02
	Computer	47	19.7	8.2	
Vocabulary	Paper	25	18.4	3.4	-.03
	Computer	47	18.5	3.1	
Word reading	Paper	25	54.2	7.2	.06
	Computer	47	53.5	12.7	

^a Effect-sizes were calculated using Cohen's *d*. Cohen's $d = M_1 - M_2 / \sigma_{\text{pooled}}$, where $\sigma_{\text{pooled}} = \sqrt{[(\sigma_{12} + \sigma_{22})/2]}$. All these effect-sizes are small.

Table 2
Sequential regression with reading comprehension scores in the main study as the outcome.

Step	Variable	R ²	R ² change	F change	β ^a	p-Value [*]
1		.35	.35	12.03		
	Vocabulary				.26	<.001
	Word reading				.31	.019
	Reading comprehension pretest				.19	.005
2		.37	.02	2.47		
	Vocabulary				.27	.094
	Word reading				.26	.121
	Reading comprehension pretest				.19	.014
	Sex				.16	.025
3		.42	.04	5.24		
	Vocabulary				.27	.098
	Word reading				.24	.121
	Reading comprehension pretest				.19	.010
	Sex				.17	.029
	Reading modality				-.21	.082

Bold values pertain to the omnibus step-values in the multiple regression.

^a β is standardized.

* p-Value is considered statistically significant at $p < .05$.

modality was found to be statistically significant ($\beta = -.216, p = .025$) indicating that students who read texts digitally were more likely to receive lower scores on the reading comprehension tests compared to the students who read the texts on paper.

There were no significant difference between the narrative text and the expository text with regard to reading modality, $F(1,70) = .142, p = .707$.

4. Discussion

The aim of the present study was to investigate the potential impact of the reading modality on certain aspects of reading comprehension. Based on existing research, we predicted that subjects in the print reading condition would perform better on the reading comprehension test than subjects in the computer reading condition. Our findings provided support for this hypothesis. Subjects who read the texts on paper performed significantly better than subjects who read the texts on the computer screen. Our second prediction was that comprehension performance would be more negatively affected by computer presentation for the expository text than for the narrative text. This hypothesis was not supported by our data, as there were no differences for the two types of text genre (i.e., narrative and expository) with regard to reading modality.

There are several possible explanations why, in the present study, subjects in the print condition scored significantly higher on the comprehension tests than those in the screen condition. Considering the length of the stimulus text, and the fact that the computer condition text was in PDF format, the difference in comprehension performance between the print and the computer group could be related to issues of *navigation* within the document. When reading on screen, scrolling is inevitable unless the text is within the screen size. Scrolling is known to hamper the process of reading, by imposing a spatial instability which may negatively affect the reader's mental representation of the text and, by implication, comprehension (Baccino, 2004; Eklundh, 1992; Piolat, Roussey, & Thunin, 1997). By presenting the texts as PDFs, we intended to minimize the potentially negative effects of scrolling. However, the scrolling option was not excluded from our material. We have no data showing whether or not, and to what extent, the students in the computer condition used the scrolling option when reading the texts. Hence, it cannot be eliminated that students in the computer condition scrolled during reading, and that this scrolling negatively impacted their comprehension performance.

Another navigation issue is related to the ways in which the two types of media determine and restrict one's access to the texts in their entirety. Evidence suggests that readers often recall where in a text some particular piece of information

appeared (e.g., toward the upper right corner or at the bottom of the page) (Piolat et al., 1997; Rothkopf, 1971; Zechmeister & McKillip, 1972). We know from empirical and theoretical research that having a good spatial mental representation of the physical layout of the text supports reading comprehension (Baccino & Pynte, 1994; Cataldo & Oakhill, 2000; Kintsch, 1998; Piolat et al., 1997). For instance, Cataldo and Oakhill (2000) found that good comprehenders were significantly better than poor comprehenders at remembering and relocating the order of information in a text, hence implying a relation between mental reconstruction of text structure and reading comprehension. To this effect, the *fixity* of text printed on paper supports reader's construction of the spatial representation of the text by providing unequivocal and fixed spatial cues for text memory and recall. In order to appropriately respond to the multiple choice questions, the subjects in our study were required to locate, access and retrieve essential pieces of information in the two texts. It is known that comprehension tasks become more difficult when the information required to complete a task, such as answering questions in a reading comprehension assessment, is not immediately visible, for instance, when the reader has to integrate information occurring at locations in a text which are spatially far apart (OECD, 2011). Such integration requires that the reader has constructed a solid mental representation of the structure of the text. Even with the relatively short texts in our study (4 pages), it is not unreasonable to assume that the intangibility of the digital text might have challenged the readers' mental reconstruction of the physical layout of the text, which in turn might have impeded their overview as well as ability to access, locate and retrieve required pieces of textual information.

Readers in the paper condition had immediate access to the text in its entirety. This access is, moreover, built on both visual and tactile cues: the reader can see as well as tactilely feel the spatial extension and physical dimensions of the text, as the material substrate of paper provides physical, tactile, spatiotemporally fixed cues to the length of the text (Mangen, 2006, 2010; Sellen & Harper, 2002). Readers in the computer condition, by contrast, were restricted to seeing (and sensing) only one page of the text at any given time of reading. Hence, their overview of the organization, structure and flow of the text (Eklundh, 1992; Piolat et al., 1997) might have been hampered due to limited access to the text in its entirety. As noted by Kerr and Symons (2006), "difficulties in reading from computers may be due to disrupted mental maps of the text, which may be reflected in poorer understanding and ultimately poorer recall of presented material" (p. 5). Admittedly, the potential role of voluminosity and thickness of paper versus screens is of limited relevance in the present study considering the length of the texts in question. A suggestion for future research could be to replicate the findings of our study and have subjects read longer (and potentially more complex) texts, as it might be assumed that challenges pertaining to intratextual navigation (i.e., navigation inside a textual document) might increase with the length of the text.

The response mode (in this case, responding to multiple choice-questions online) might also explain why subjects reading on paper performed better than those reading on computer screens. Whereas, in the paper condition, the task of responding to questions involved switching between the two media (i.e., between the texts on paper on the desk and the questions on a laptop computer screen), subjects in the computer condition had to switch between different windows on the computer, one displaying the text to be read, the other displaying the questions to be answered. As found also in a previous study (Wästlund et al., 2005), the dual-task involved in switching between two windows displayed on the same computer screen is likely to present additional cognitive challenges to the reader. This finding is an illustrating example of how the ease of *multitasking* provided by the computer might come at a cognitive cost, something which is evidenced in a number of studies (Bowman, Levine, Waite, & Gendron, 2010; Fox, Rosen, & Crawford, 2009; Kirschner & Karpinski, 2010; Lin, 2009; Lin, Robertson, & Lee, 2009; Ophir, Nass, & Wagner, 2009).

Another potential explanation might be related to differences at a *metacognitive* level. Metacognition, or the ability to monitor one's cognitive performance, has been shown to correlate with good reading comprehension (Garner, 1987; Paris, Wasik, & Turner, 1991). A recent study by Ackerman and Goldsmith (2011) is particularly interesting in this regard. Comparing reading performance from On-Screen Learning (OSL) and On-Paper Learning (OPL), the authors found that under fixed study time (Experiment 1), test performance did not differ significantly. However, when study time was self-regulated (Experiment 2), poorer performance was observed in screen reading than in paper reading. The lower test performance of OSL was accompanied by significant overconfidence with regard to predicted performance (shorter study time + lower level of actual learning), whereas subjects in the OPL group monitored their performance more accurately. Ackerman and Goldsmith (2011) conclude that people appear to perceived the medium of print as more suitable for effortful learning, whereas the electronic medium (in this case, a computer) is better suited for "fast and shallow reading of short texts such as news, e-mails, and forum notes [...]. The common perception of screen presentation as an information source intended for shallow messages may reduce the mobilization of cognitive resources that is needed for effective self-regulation" (p. 29). In the present study, we did not measure the reading time. Hence, we cannot say if subjects in the computer screen condition spent more time reading than the subjects in the print condition. A suggestion for future studies on digital reading is to combine objective reading time measures with both subjective and objective measures of reading performance.

Print and screen media also differ with respect to *visual ergonomics*. Hence, some of the explanation for the differences between screen reading and print reading might relate to the different lighting conditions in the two modalities. LCD computer screens like the ones used in this study are known to cause visual fatigue due to their emitting light. In contrast, e-book technologies based on electronic ink, such as Kindle and Kobo, are merely reflecting light and are hence more reader friendly with respect to the visual ergonomics. Studies by, e.g., Garland and Noyes (2004) and Noyes and Garland (2003), concluded that certain features of the LCD screen, such as refresh rate, contrast levels and fluctuating light interfere with cognitive processing and hence potentially impair long-term memory. LCD screen technologies differ from both print and more print-like screen displays based on electronic ink in that LCD screens as found in most computers and surf tablets (such

as the iPad) are emitting light, whereas e-book technologies based on electronic ink, such as the Kindle, are reflecting ambient light. Light-emitting screens are known to cause visual fatigue and, more specifically, computer vision syndrome (Baccino, 2004; Blehm, Vishnu, Khattak, Mitra, & Yee, 2005; Yan, Hu, Chen, & Lu, 2008). The visuospatial, perceptual processes of reading, involving letter detection and word identification, depend crucially on the visual legibility of the text. The visual legibility of the text, in turn, is influenced by several factors, among which the screen resolution, effects of backlighting, and luminance contrast (Dillon & Emurian, 1995; Lee, Ko, Shen, & Chao, 2011). The deteriorating effects on the visual processing of text might in turn have negative implications for higher-level processes such as comprehension.

It is impossible to determine from the data of the current study whether visual fatigue contributed to the poorer reading comprehension performance in the computer condition. Hence, we cannot say whether the visual ergonomics of the laptop computer screens had a negative impact on subjects' reading. In future studies, employing online measures including eye tracking methods would be a way of appropriately addressing this important issue.

5. Conclusion

The results of this study indicate that reading linear narrative and expository texts on a computer screen leads to poorer reading comprehension than reading the same texts on paper. These results have several pedagogical implications. Firstly, we should not assume that changing the presentation format for even short texts used in reading assessments will not have a significant impact on reading performance. If texts are longer than a page, scrolling and the lack of spatiotemporal markers of the digital texts to aid memory and reading comprehension might impede reading performance. Furthermore, our results suggest that implementing both reading assessment tasks (i.e., text reading and response tasks) in the same medium – the computer – leads to additional cognitive costs. Hence, the ongoing digitization of response format in the Norwegian educational assessment system warrants extra consideration of important but hitherto largely neglected factors potentially influencing assessment outcomes, such as challenges pertaining to multitasking in a digital environment.

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.
- Baccino, T. (2004). *La lecture électronique: De la vision à la compréhension*. Grenoble: Presses Universitaires de Grenoble.
- Baccino, T., & Pynte, J. (1994). Spatial coding and discourse models during text reading. *Language and Cognitive Processes*, 9, 143–155.
- Belsley, D. A., Kuh, E., & Welsch, R. E. (1980). *Regression diagnostics: Identifying influential data and sources of collinearity*. New York: Wiley.
- Blehm, C., Vishnu, S., Khattak, A., Mitra, S., & Yee, R. W. (2005). Computer vision syndrome: A review. *Survey of Ophthalmology*, 50(3), 253–262.
- Bowman, L. L., Levine, L. E., Waite, B. M., & Gendron, M. (2010). Can students really multitask? An experimental study of instant messaging while reading. *Computers and Education*, 54(4), 927–931.
- Buch-Iversen, I. (2010). *Betydningen av inferens for leseforståelse [The role of inferences in reading comprehension]*. Doctoral thesis, University of Stavanger, Norway. Retrieved from http://brage.bibsys.no/uis/handle/URN:NBN:no-bibsys_brage_13096.
- Cataldo, M. G., & Oakhill, J. (2000). Why are poor comprehenders inefficient searchers? An investigation into the effects of text. *Journal of Educational Psychology*, 92(4), 791–799.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2 ed.)*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Coniam, D. (2011). A qualitative examination of the attitudes of Liberal Studies markers towards onscreen marking in Hong Kong. *British Journal of Educational Technology*, 42(6), 1042–1054.
- Conway, M. A., Gardiner, J. M., Perfect, T. J., Anderson, S. J., & Cohen, G. (1997). Changes in memory awareness during learning: The acquisition of knowledge by psychology undergraduates. *Journal of Experimental Psychology: General*, 126(4), 393–413.
- DeStefano, D., & Lefevre, J.-A. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior*, 23(3), 1616–1641.
- Dillon, A. (1992). Reading from paper versus screens: A critical review of the empirical literature. *Ergonomics*, 35(10), 1297–1326.
- Dillon, T. W., & Emurian, H. H. (1995). Reports of visual fatigue resulting from use of video display unit. *Computers in Human Behavior*, 11(1), 77–84.
- Eklundh, K. S. (1992). Problems in achieving a global perspective of the text in computer-based writing. *Instructional Science*, 21(1), 73–84.
- Fox, A. B., Rosen, J., & Crawford, M. (2009). Distractions, distractions: Does instant messaging affect college students' performance on a concurrent reading comprehension task? *Cyberpsychology and Behavior*, 12(1), 51–53.
- Garland, K. J., & Noyes, J. M. (2004). CRT monitors: Do they interfere with learning? *Behaviour and Information Technology*, 23(1), 43–52.
- Garner, R. (1987). *Metacognition and reading comprehension*. Westport, CT: Ablex Publishing.
- Graesser, A. C., Millis, K. K., & Zwaan, R. A. (1997). Discourse comprehension. *Annual Review of Psychology*, 48, 163–189.
- Herbert, D. M. B., & Burt, J. S. (2001). Memory awareness and schematization: Learning in the university context. *Applied Cognitive Psychology*, 15, 617–637.
- Høien, T., & Tønnesen, G. (2008). *Instruksjonshefte til ordkjedetesten*. [Manual for the word-chain test]. Bryne: Logometrica.
- Johnson, M., Hopkin, R., & Shiell, H. (2011). Extended essay marking: Does the transition from paper to screen influence examiners' cognitive workload? *International Journal of e-Assessment*, 1(1), 107–124.
- Johnson, M., & Nádás, R. (2009). Marginalised behaviour: Digital annotations, spatial encoding and the implications for reading comprehension. *Learning, Media and Technology*, 34(4), 323–336.
- Johnson, M., Nádás, R., & Bell, J. F. (2010). Marking essays on screen: An investigation into the reliability of marking extended subjective texts. *British Journal of Educational Technology*, 41(5), 814–826.
- Kerr, M. A., & Symons, S. E. (2006). Computerized presentation of text: Effects on children's reading of informational material. *Reading and Writing*, 19(1), 1–19.
- Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. Cambridge: Cambridge University Press.
- Kirschner, P. A., & Karpinski, A. C. (2010). Facebook[®] and academic performance. *Computers in Human Behavior*, 26(6), 1237–1245.
- Lee, D.-S., Ko, Y.-H., Shen, I.-H., & Chao, C.-Y. (2011). Effect of light source, ambient illumination, character size and interline spacing on visual performance and visual fatigue with electronic paper displays. *Displays*, 32(1), 1–7.
- Lie, S., Kjærnsli, M., Roe, A., & Turmo, A. (2001). *Godt rustet for framtida? Norske 15-åringers kompetanse i lesing og realfag i et internasjonalt perspektiv [Well prepared for the future? Reading and writing skills of Norwegian 15-year olds in an international perspective]*. Oslo: University of Oslo, Institutt for Lærerutdanning og Skoleutvikling.
- Lin, L. (2009). Breadth-biased versus focused cognitive control in media multitasking behaviors. *PNAS: Proceedings of the National Academy of Sciences of the United States of America*, 106(37), 15521–15522.
- Lin, L., Robertson, T., & Lee, J. (2009). Reading performances between novices and experts in different media multitasking environments. *Computers in the Schools*, 26(3), 169–186.

- Mangen, A. (2006). *New narrative pleasures? A cognitive-phenomenological study of the experience of reading digital narrative fictions*. Doctoral thesis, Norwegian University of Science and Technology [NTNU], Trondheim, Norway. Retrieved from <http://urn.kb.se/resolve?urn=urn:nbn:no:ntnu:diva-1833>.
- Mangen, A. (2010). Point and click: Theoretical and phenomenological reflections on the digitization of early childhood education. *Contemporary Issues in Early Childhood* 11(4).
- Noyes, J. M., & Garland, K. J. (2003). VDT versus paper-based text: Reply to Mayes, Sims and Koonce. *International Journal of Industrial Ergonomics*, 31, 411–423.
- Noyes, J. M., & Garland, K. J. (2008). Computer- vs. paper-based tasks: Are they equivalent? *Ergonomics*, 51(9), 1352–1375.
- OECD. (2011). *PISA 2009 results: Students on line: Digital technologies and performance* (Vol. VI, pp.). OECD.
- Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *PNAS: Proceedings of the National Academy of Sciences of the United States of America*, 106(37), 15583–15587.
- Paris, S. G., Wasik, B. A., & Turner, J. C. (1991). The development of strategic readers. In Barr, R., Kamil, M. L., Mosenthal, P. B., & Pearson, P. D. (Eds.), *Handbook of reading research* (Vol. II, pp. 609–640). New York: Longman.
- Piolat, A., Roussey, J.-Y., & Thunin, O. (1997). Effects of screen presentation on text reading and revising. *International Journal of Human-Computer Studies*, 47(4), 565–589.
- Reinking, D. (1988). Computer-mediated text and comprehension differences: The role of reading time, reader preference, and estimation of learning. *Reading Research Quarterly*, 23(4), 484–498.
- Rice, G. E. (1994). Examining constructs in reading comprehension using two presentation modes: Paper vs. computer. *Journal of Educational Computing Research*, 11(2), 153–178.
- Rothkopf, E. (1971). Incidental memory for location of information in text. *Journal of Verbal Learning and Behavior*, 10, 608–613.
- Sellen, A. J., & Harper, R. H. R. (2002). *The myth of the paperless office*. Cambridge, MA: MIT Press.
- Tulving, E. (1985). Memory and consciousness. *Canadian Psychology*, 26, 1–12.
- Wästlund, E. (2007). *Experimental studies of human-computer interaction: Working memory and mental workload in complex cognition*. Göteborg: Department of Psychology, Gothenburg University.
- Wästlund, E., Reinikka, H., Norlander, T., & Archer, T. (2005). Effects of VDT and paper presentation on consumption and production of information: Psychological and physiological factors. *Computers in Human Behavior*, 21, 377–394.
- Yan, Z., Hu, L., Chen, H., & Lu, F. (2008). Computer vision syndrome: A widely spreading but largely unknown epidemic among computer users. *Computers in Human Behavior*, 24(5), 2026–2042.
- Zechmeister, E. B., & McKillip, J. (1972). Recall of place on the page. *Journal of Educational Psychology*, 63(5), 446–453.