Investigating the Mechanisms Underlying Differences in Reading Outcomes Across Media: A Postprint

Authors: Zhaohui Duan, Hong Jianzhong, Wang Fuxing

Date: 2023-08-26T00:00:00+00:00

Abstract

[Purpose/Significance]To better disseminate knowledge and improve reading effectiveness, this study examines the differences in reading outcomes between electronic and paper-based reading, and experimentally investigates the mechanisms influencing medium-specific reading effectiveness.[Method/Process]Through experimentation, we compared the reading outcomes of learners under three conditions: paper-based reading (P-book) with high contextual information level, iReader electronic reading with medium contextual information level, and Word electronic reading with low contextual information level.[Results/Conclusion]The results revealed that: Under the P-book condition, learners demonstrated significantly superior performance compared to the Word condition on transfer tests, cognitive load, reading speed, and visual fatigue, and also significantly outperformed the iReader group on transfer tests. The iReader group showed significantly better performance than the Word group on reading speed and cognitive load. It is concluded that reading effectiveness is simultaneously influenced by both reading medium and contextual information cues in the reading environment. Contextual information cues in the paper-based reading environment can alleviate visual fatigue, reduce cognitive load, and improve reading speed; however, knowledge comprehension in reading effectiveness is more susceptible to the influence of reading medium, with paper media being more conducive to knowledge comprehension.

Full Text

Preamble

ChinaXiv Collaborative Journal
Volume 62, Issue 12, June 2018

Exploring the Mechanism of Differential Reading Effects Across Different Media

Duan Chaohui, Hong Jianzhong, Wang Fuxing
School of Psychology, Central China Normal University, Wuhan 430079

Abstract: [Purpose/Significance] To better disseminate knowledge and improve reading effectiveness, this study investigates the mechanism underlying differential reading effects across media through an experimental comparison of electronic and paper-based reading. [Method/Process] The experiment compared learners' reading performance across three conditions: paper-based reading with high background information level (P-book), iReader electronic reading with medium background information level, and Word electronic reading with low background information level. [Results/Conclusions] Results showed that the P-book condition yielded significantly better performance than the Word condition in transfer tests, cognitive load, reading speed, and visual fatigue, and also outperformed the iReader group in transfer tests. The iReader group performed significantly better than the Word group in reading speed and cognitive load. The study concludes that reading effectiveness is simultaneously influenced by reading medium and background information cues in the reading environment. Background information cues in paper-based reading environments can alleviate visual fatigue, reduce cognitive load, and improve reading speed; however, knowledge comprehension in reading outcomes is more susceptible to the influence of reading medium, with paper media being more conducive to knowledge understanding.

Classification Number: G442
Keywords: paper reading, electronic reading, reading medium, cognitive map, comprehension transfer
DOI: 10.13266/j.issn.0252-3116.2018.12.009

With the rise of electronic media such as the internet and the promotion of digital text, electronic reading has become increasingly important in people's lives. Researchers anticipated decades ago that with the emergence and popularization of PDAs, e-readers (such as Kindle), and mobile phones, electronic reading would likely eventually replace paper reading [1]. However, paper reading habits persist in people's work, study, and daily life. What exactly are the differences in reading effectiveness between paper and electronic texts, and what factors influence these differences? This study addresses these questions through experimental investigation.

1.1 Comparative Research on Electronic and Paper Reading

Existing comparative studies between electronic and paper texts have primarily focused on four aspects: memory retention, transfer effects, reading speed, and visual fatigue. Studies on memory retention show no difference between electronic and paper reading [1-4]. Memory retention is typically measured using multiple-choice and recognition tests [5]. For instance, Mutter et al. had participants read novels on electronic screens and in books without allowing backtracking, then administered 25 multiple-choice questions, finding no differences between the two conditions [2, 6]. Similarly, P.C. Chang et al. [1] used participants without prior knowledge, had them read earthquake-related materials on e-readers with different illumination and resolution settings, and compared them with paper books, again finding no difference in accuracy when identifying knowledge content.

However, findings on comprehension tests have been inconsistent. Some researchers using middle school students found that those reading on paper demonstrated better reading comprehension and summarization than those reading on computers [8], while others using college students and elderly participants found no differences between electronic and paper reading in comprehension tests [9].

Reading speed, as an indicator of reading effectiveness, has consistently shown that electronic reading is slower than paper reading [10-11]. Specifically, reading the same content on electronic media is 20-30% slower than using paper books [10-11]; even when skimming (reading at 3-4 times normal speed to grasp general content), electronic reading remains 41% slower [2]. Research on visual fatigue has also found that under the same reading task conditions, electronic readers experience more eye strain and visual fatigue than paper readers [1, 12].

1.2 Theoretical Foundation

The above research [4, 11] shows consistent conclusions regarding reading speed, visual fatigue, and memory retention: paper reading is faster, less visually fatiguing, and more preferred, with no difference in memory retention. However, comprehension transfer effects show either better performance with paper reading or no difference [8-9]. Why do these inconsistent results occur? Two main theoretical perspectives address this phenomenon: the reading medium mechanism and the cognitive map mechanism.

The reading medium mechanism explains these differences based on the inherent properties of the reading medium itself [3, 13]. In electronic reading conditions, people must not only process electronic text information but also operate tools such as a mouse, resulting in higher extraneous cognitive load. Consequently, with the same learning task and working memory capacity, learners have fewer resources available for text processing, leading to poorer reading outcomes [3]. Additionally, the high-brightness electronic screen in electronic reading creates extra cognitive load, particularly causing physiological visual fatigue [13]. Paper reading avoids these problems, providing a more natural environment that aligns with established reading habits.

The cognitive map mechanism posits that cognitive maps constructed in the brain closely resemble the spatial distribution of objects in the physical environment [14]. In physical maps, more landmarks and routes make locating target objects easier. Similarly, more background cues and markers in a cognitive map improve knowledge memory and retrieval [15]. In reading, compared to e-books, printed books provide more background information: eight corners of an opened book, front and back pages, visible chapter starting pages, perceptible book thickness, tactile paper, page numbers, etc. These background cues enter the brain during reading to participate in mental representation construction, helping learners build cognitive schemas and resulting in better reading experiences and outcomes [16-17]. In contrast, electronic reading conditions offer minimal spatial background information per page and include distracting elements like hyperlinks, making spatial localization of knowledge from different pages difficult and providing fewer identifiable cues in the cognitive map [18], thus increasing cognitive load during memory and retrieval [18].

1.3 Research Hypotheses

To better reveal the mechanisms of these two theories in media reading, this study designed three conditions: paper reading (P-book), iReader electronic reading, and Word electronic reading. The P-book condition used traditional printed books with markers including eight page corners, page numbers, visual reading progress, visual page-turning, and tactile sensation (perceiving paper thickness and reading progress). The iReader condition used iReader software simulating a printed book environment, with identical markers to P-book except for lack of physical paper contact. The Word condition used Microsoft Word software, removing four page corners (single-page reading), page numbers, visual page-turning, and visual thickness, while retaining a basic relative reading progress indicator—reflecting common reading habits. Across these three conditions, P-book had the highest background information level, iReader had medium, and Word had low.

If the reading medium perspective is correct, then compared to the paper P-book condition, learners in electronic reading conditions (Word and iReader) would show poorer memory retention and transfer effects, higher visual fatigue, and slower reading speed, with no significant differences between the two electronic conditions (Hypothesis 1).

If the cognitive map perspective is correct, then conditions with more background information cues would show better memory retention and transfer effects, lower visual fatigue, and faster reading speed, following the trend: P-book > iReader > Word (Hypothesis 2).

2.1 Participants and Design

The experiment employed a single-factor, three-level between-subjects design. The three reading conditions were: paper reading with high background information (P-book), electronic reading with medium background information (iReader), and electronic reading with low background information (Word). Specific marker information for each group is described in Section 1.3. Experimental treatments for the three conditions are shown in Figure 1 [Figure 1: see original paper].

Participants were 76 college students with electronic reading experience recruited through convenience sampling at a university, using paid recruitment and course credit incentives. They were randomly assigned to three groups: P-book group (n = 25, 4 male), mean age 20.16 years (SD = 1.95); Word group (n = 25, 2 male), mean age 20.16 years (SD = 2.13); and iReader group (n = 26, 3 male), mean age 20.27 years (SD = 2.24).

To prevent prior knowledge from affecting reading outcomes [23], all participants were low prior-knowledge individuals scoring below 28 points (70% cutoff following previous research [22, 24]) on a pre-test knowledge questionnaire.

2.2 Materials

Reading Material: Following previous research [20], we selected accessible, life-relevant economics knowledge. As this was lengthy reading requiring at least 30 minutes in pilot testing, we ensured content interest by selecting material from *Fun Economics* [21]. The experimental content comprised the book cover through the end of Chapter 1, which contained 13 sections across 58 pages.

Pre-test Questionnaire: Developed by our research team, including demographics and an economics knowledge pre-test. The knowledge pre-test, adapted from previous studies [22], contained 8 items rated on 5-point scales (1 = "very little" to 5 = "very much"), with total scores ranging from 8 to 40.

Post-test Questionnaire: Included 4 retention test items and 4 transfer test items, adapted from relevant research [22, 25]. Retention tests used multiple-choice format with answers directly found in the reading material (total score = 8). Transfer tests used short-answer format with items designed to assess flexible application of knowledge (total score = 8). Two trained raters scored the post-tests, achieving inter-rater reliability of $r = 0.96$ ($p < 0.001$) for retention and $r = 0.93$ ($p < 0.001$) for transfer; final scores used the average.

Visual Fatigue Scale: Used subjective ratings adapted from P.C. Chang et al. [1] with modifications, comprising 6 items: difficulty seeing, unusual eye sensations, eye tiredness, eye numbness, headache, and screen dizziness. Each item used a 7-point Likert scale (1 = "not at all" to 7 = "very strongly"), scored 0-6, with total scores ranging from 0 to 36.

Cognitive Load Scale: Assessed cognitive load by rating content difficulty and task effort during reading and questionnaire completion [26-27], including 4 items: reading content difficulty, reading effort, questionnaire difficulty, and questionnaire effort [28]. Each used a 7-point Likert scale (1 = "very easy" to 7 = "very difficult"), scored 0-6.

2.3 Apparatus and Procedure

Electronic reading groups used Dell desktop computers: Word group used Microsoft Word 2010, iReader group used iReader software. The P-book group read printed books directly. Reading time was recorded using a stopwatch.

Procedure: The experiment consisted of six stages: (1) Pre-test screening and random assignment; (2) Instruction and formal experiment—participants were instructed to read from the cover through Chapter 1 without note-taking, with no time limit but time recorded; (3) After reading, participants completed a 50-item serial subtraction by 7 task as a memory interference task (3-5 minutes); (4) Subjective ratings: reading difficulty, reading effort, visual fatigue, and continued reading tendency; (5) Retention and transfer tests; (6) Questionnaire difficulty and effort ratings.

To address potential context-dependent memory effects [19], electronic reading groups received electronic versions of pre- and post-test questionnaires, while the paper group received paper versions.

Results

All dependent variables were analyzed using one-way ANOVA, with LSD post-hoc tests for significant main effects. Detailed scores are presented in Table 1 .

Table 1 Experimental Data Across Questionnaires

Measure	P-book	iReader	Word	F(2,73)
Pre-test knowledge	17.36	16.32	16.03	2.40#
Reading time (min)	29.43	35.60	13.36	6.72**
Visual fatigue	-1.16	-0.24	13.18	7.43**
Retention test^a	11.80	13.18	16.32	3.03#
Transfer test^a	16.32	13.18	11.80	3.88*
Cognitive load^a	29.32	13.18	16.03	3.24*

Note: ^a = with reading time and gender as covariates (df error = 71); * $p < 0.05$, ** $p < 0.01$, # marginally significant

Pre-test knowledge scores did not differ significantly across conditions, indicating that post-test results were not influenced by prior knowledge.

Reading time showed a marginally significant main effect ($p = 0.098$). Post-hoc tests revealed that the Word group read significantly longer than the P-book group ($p = 0.065$) and iReader group ($p = 0.058$), with no significant difference between P-book and iReader groups.

Visual fatigue showed a significant main effect. Post-hoc tests indicated that the Word group experienced significantly higher visual fatigue than the P-book group, but no significant difference between P-book and iReader groups.

For the retention test, the main effect was marginally significant ($p = 0.054$). The Word group scored significantly higher than the P-book group, but no other pairwise differences were significant. When reading time and gender were included as covariates, the difference across conditions became non-significant, indicating that reading time accounted for the Word group's higher retention scores.

Transfer test results showed a significant main effect. The P-book group significantly outperformed both the iReader and Word groups, while the iReader group scored higher than the Word group but not significantly. After controlling for reading time and gender, the P-book group still significantly outperformed the Word group.

Cognitive load (computed by converting four component ratings to Z-scores and summing them) showed a significant main effect. The Word group experienced significantly higher cognitive load than both the iReader and P-book groups, with no significant difference between the latter two.

Discussion

This study examined the mechanisms underlying differential reading effects across media by comparing a high-background-information paper reading condition (P-book), a medium-background-information electronic condition (iReader), and a low-background-information electronic condition (Word). Results showed that the P-book group outperformed the Word group in transfer tests, cognitive load, reading speed, and visual fatigue, and also outperformed the iReader group in transfer tests. The iReader group performed better than the Word group across these measures, though significantly so only for reading speed and cognitive load. We conclude that reading performance is influenced by both reading medium and background information cues in the reading environment. Background cues in paper-based environments can alleviate visual fatigue, reduce cognitive load, and improve reading speed; however, knowledge comprehension is more susceptible to reading medium effects, with paper books being more conducive to knowledge understanding.

The reading medium mechanism was supported regarding transfer effects. This aligns with previous research showing better comprehension with paper reading

[8], confirming that reading on electronic screens impairs understanding [29]. According to activity theory, tool use in the environment affects cognitive socialization and social-cognitive skill acquisition [30]. Electronic tools like screens and mice may affect reading cognitive processing [31], with toolbars, hyperlinks, and scrollbars in Word increasing cognitive load and attentional interference, thereby impairing comprehension [32].

While the cognitive map mechanism was not fully supported for transfer effects, we speculate that mental map construction in reading comprehension is substantially related to hand sensory experiences and actions, particularly touch. Fortunati and Vincent [33] found through qualitative analysis that university students experience more multi-sensory engagement and meta-communicative feelings during paper reading, with manual page-turning and writing providing more benefits than mouse and keyboard use [34]. The iReader condition's lack of tactile sensory experience may have hindered cognitive map construction or retrieval for transfer effects.

However, the cognitive map mechanism was supported for cognitive load, visual fatigue, and reading speed. According to this perspective, readers construct mental maps of knowledge based on spatial information distribution across pages [18]. Paper environments provide rich background cues that facilitate cognitive map construction and reduce cognitive load and visual fatigue [16-17]. Electronic environments lack these spatial cues [10], hindering effective cognitive map construction [15] and increasing cognitive load. This aligns with previous research on cognitive load [3] and visual fatigue [1].

Limitations and Future Directions

This study has two limitations. First, we used lengthy learning materials requiring over 30 minutes of reading, which are more difficult and demanding than narrative texts. This limits generalizability to novel reading, though previous research on novels [20] and comic books [18] also favors paper reading. Future research should compare different text types. Second, our study used single-task reading environments, whereas real-world electronic reading often occurs in multi-tasking contexts with higher cognitive load and working memory demands. Future studies should explore multi-tasking environments, which are more ecologically valid.

References

[1] CHANG P C, CHOU S Y, SHIEH K K. Reading performance and visual fatigue when using electronic paper displays in long-duration reading tasks under various lighting conditions[J]. Displays, 2013, 34(3): 208-214.

[2] MUTER P, MAURUTTO P. Reading and skimming from computer screens and books: the paperless office revisited?[J]. Behaviour & information technology, 1991, 10(4): 257-266.

[3] NOYES J M, GARLAND K J, ROBBINS L. Paper-based versus computer-based assessment: is workload another test mode effect?[J]. British journal of educational technology, 2004, 35(1): 111-113.

[4] RICHTER A, COURAGE M L. Comparing electronic and paper storybooks for preschoolers: attention, engagement, and recall[J]. Journal of applied developmental psychology, 2017, 48: 92-102.

[5] WOODWORTH, SCHLOSBERG. Experimental Psychology[M]. Translated by CAO Richang, SUN Guohua, TANG Yue, et al. Beijing: Peking University Press, 2014.

[6] KRUK R S, MUTER P. Reading of continuous text on video screens[J]. Human factors: the journal of the human factors and ergonomics society, 1984, 26(3): 339-345.

[7] DANEMAN M, CARPENTER P A. Individual differences in working memory and reading[J]. Journal of verbal learning and verbal behavior, 1980, 19(4): 450-466.

[8] MANGEN A, WALGERMO B R, BRØNNICK K. Reading linear texts on paper versus computer screen: effects on reading comprehension[J]. International journal of educational research, 2013, 58(2): 61-68.

[9] KRETZSCHMAR F, PLEIMLING D, HOSEMANN J, et al. Subjective impressions do not mirror online reading effort: concurrent EEG-eye-tracking evidence from the reading of books and digital media[J]. PloS one, 2013, 8(2): e56178.

[10] DILLON A. Reading from paper versus screens: a critical review of the empirical literature[J]. Ergonomics, 1992, 35(10): 1297-1326.

[11] SUBRAHMANYAM K, MICHIKYAN M, CLEMMONS C, et al. Learning from paper, learning from screens: impact of screen reading and multitasking conditions on reading and writing among college students[J]. International journal of cyber behavior, psychology and learning, 2013, 3(4): 1-27.

[12] KANG Y Y, WANG M J J, LIN R. Usability evaluation of e-books[J]. Displays, 2009, 30(2): 49-52.

[13] MARGOLIN S J, DRISCOLL C, TOLAND M J, et al. E-readers, computer screens, or paper: does reading comprehension change across media platforms?[J]. Applied cognitive psychology, 2013, 27(4): 512-519.

[14] SPENCE. A framework for navigation[J]. International journal of human-computer studies, 1999, 51(5): 919-945.

[15] LI L Y, CHENG D, YANG S J. Construction of cognitive maps to improve e-book reading and navigation[J]. Computers & education, 2013, 60(1): 32-39.

[16] JABR F. The reading brain in the digital age: the science of paper versus screens[J]. Scientific American, 2013, 309(5): 48-53.

[17] CHANGIZI M. The problem with the web and e-books is that there's no space for them[EB/OL]. [2011-02-07]. http://www.psychologytoday.com/blog/nature-brain-and-culture/201102/the-problem-the-web-and-e-books-is-there-s-no-space-for-them.

[18] HOU J, RASHID J, LEE K M. Cognitive map or medium materiality? Reading on paper and screen[J]. Computers in human behavior, 2017, 67(2): 84-94.

[19] GODDEN D R, BADDELEY A D. Context-dependent memory in two natural environments: on land and underwater[J]. British journal of psychology, 1975, 66(3): 325-331.

[20] MUTER P, LATREMOUILLE S A, TREURNIET W C, et al. Extended reading of continuous text on television screens[J]. Human factors: the journal of the human factors and ergonomics society, 1982, 24(5): 501-508.

[21] CAO Yongguan. Fun Economics[M]. Beijing: Publishing House of Electronics Industry, 2011.

[22] MAYER R E. Research-based principles for the design of instructional messages: the case of multimedia explanations[J]. Document design, 1999, 1(1): 7-19.

[23] KALYUGA S, AYRES P, CHANDLER P, et al. The expertise reversal effect[J]. Educational psychologist, 2003, 38(1): 23-31.

[24] DUAN Chaohui, YAN Zhiqiang, WANG Fuxing, et al. An eye-movement study on the effects of animation presentation speed on multimedia learning[J]. Psychological Development and Education, 2013, 29(1): 46-52.

[25] MUTER P. Interface design and optimization of reading of continuous text[C]// VAN OOSTENDORP H, DE MUL S. Cognitive aspects of electronic text processing. Norwood: Ablex Publishing, 1996: 161-180.

[26] KALYUGA S, CHANDLER P, SWELLER J. Managing split-attention and redundancy in multimedia instruction[J]. Applied cognitive psychology, 1999, 13(4): 351-371.

[27] PAAS F G, VAN MERRIËNBOER J J. Instructional control of cognitive load in the training of complex cognitive tasks[J]. Educational psychology review, 1994, 6(4): 351-371.

[28] JIN B L, BAI H X. Synthetic assessment of cognitive load in human-machine interaction process[J]. Acta Psychologica Sinica, 2009, 41(1): 35-43.

[29] JIANG Hong. Can digital reading replace paper reading? A meta-analysis of 36 studies on the effects of information carriers on reading performance[J]. Shanghai Educational Research, 2017(9): 17-22.

[30] VYGOTSKY L S. Mind in society: The development of higher mental process[M]. Cambridge: Harvard University Press, 1978.

[31] NOYES J M, GARLAND K J. VDT versus paper-based text: reply to Mayes, Sims and Koonce[J]. International journal of industrial ergonomics, 2003, 31(6): 411-423.

[32] STANTON N, CORREIA A P, DIAS P. Efficacy of a map on search, orientation and access behaviour in a hypermedia system[J]. Computers & education, 2000, 35(4): 263-279.

[33] FORTUNATI L, VINCENT J. Sociological insights on the comparison of writing/reading on paper with writing/reading digitally[J]. Telematics and informatics, 2014, 31(1): 39-51.

[34] TAIPALE S. Bodily dimensions of reading and writing practices on paper and digitally[J]. Telematics and informatics, 2015, 32(4): 766-775.

Author Contributions: Duan Chaohui: data collection, analysis, and manuscript writing; Hong Jianzhong: theoretical guidance; Wang Fuxing: experimental guidance.

Note: Figure translations are in progress. See original paper for figures.