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Comparison of reading performance on screen and on paper: A meta-analysis

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ABSTRACT

This meta-analysis looked at 17 studies which focused on the comparison of reading on screen and reading on paper in terms of reading comprehension and reading speed. The robust variance estimation (RVE)- based meta-analysis models were employed, followed by four different RVE meta-regression models to examine the potential effects of some of the covariates (moderators) on the mean differences in comprehension and reading speed between reading on screen and reading on paper. The RVE meta-analysis showed that reading on paper was better than reading on screen in terms of reading comprehension, and there were no significant differences between reading on paper and reading on screen in terms of reading speed. None of the moderators were significant at the 0.05 level. In the meanwhile, albeit not significant, examination of the p-values for the difference tests prior to 2013 and after 2013 respectively (not shown here) indicated that the magnitude of the difference in reading comprehension between paper and screen followed a diminishing trajectory. It was suggested that future meta-analyses include latest studies, and other potential moderators such as fonts, spacing, age and gender.

1. Introduction

Technology has advanced rapidly in the past decades. It has spread into every corner of our lives. We use computers to do work, cell phones to keep connected with families and friends, and tablets to read books. When it comes to education, many schools are using online learning systems and devices, and/or distributing learning content in electronic format, in support of their traditional face-to-face teaching and learning. In January 2014, approximately 17,000 schools across 100 countries were using Blackboard, a well-known learning management system, to distribute reading material and carry out online discussions and other activities (Corcoran, 2014). Within the US, about 75% of colleges and universities and more than half of K-12 districts were using Blackboard's service (Empson, 2014). It is a trend that students today read much less on traditional sources such as paper, and much more on electronic sources such as computers, tablets, and cell phones (Cartelli, 2012).

As Murphy, Holleran, and Esterly (2003) stated, "the strategies requisite for comprehending traditional printed text are not the same strategies required to comprehend computerized texts" (p. 528). While researchers have been scrutinizing reading on paper for decades (see Dole, Duffy, Roehler, & Pearson, 1991; Israel & Duffy, 2014 for example), much less attention has been paid to students' on-screen reading experience, even though reading on screen has become more and more prevalent. In addition, a systematic synthesis and analysis of existing literature related to both reading on screen and reading on paper is scarce. More than two decades ago, Dillon (1992) reviewed empirical studies that "examine[d] critically the reported differences … in terms of use and thereby

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support reasoned analysis of the paper versus electronic text debate from the perspective of the reader" (p. 1298). Since then, technology has evolved dramatically, and people's views towards technology have changed greatly. Yet a structured, comprehensive, and up-to-date review of reading on screen is absent, which compromises educators' ability to provide appropriate and sufficient support to guide students to become successful readers in this digital era. In order to narrow the gap, as a pilot study, this meta-analysis reviewed various literature on the comparison of reading on screen and reading on paper since 2000 and conducted a meta-analysis to provide a more up-to-date and thorough view on this issue. Two research questions guided this study:

(1) Do reading on screen and reading on paper differ in terms of reading comprehension and speed?
(2) Do year of publication, country of study, and type of screen play a moderating role in the difference, if any, between reading on screen and reading on paper in terms of reading comprehension and speed?

We looked at types of screen because different screen types could affect readers' performance. For example, some eReaders, such as earlier versions of Kindle, only display basic and simple texts, thus contain less complexities, such as hyperlinks, images, and videos that could hinder readers' performance (Coiro, 2011). Year of publication and country of study were included as exploratory analyses.

This meta-analysis does not aim to suggest the best practice for reading on screen. Instead, it aims to synthesize and highlight the current research focus and findings when it comes to reading on screen, with the hope that it will yield affordance for future research and teaching practice.

2. Literature review

Reading is an active and complex cognitive process of meaning making. For decades, researchers have examined readers' cognitive processes (e.g., decoding, metacognition), subskills of reading, and how the use of reading strategies may help with reading comprehension and reading speed (see Israel & Duffy, 2014; Wolf & Stoodley, 2008 for example). In recent years, the introduction of digital reading media (through which the text is presented, as used in previous studies, e.g., Margolin, Driscoll, Toland, & Kegler, 2013, etc.), such as computers and tablets, has been reshaping the traditional reading paradigm (see Coiro, 2003 for example), and researchers were having mixed views towards the shift. For example, as Liu (2005) stated, reading on screen brought certain advantages which were absent on paper, such as the "interactivity, non-linearity, immediacy of accessing information, and the convergence of text and images, audio and video" (p. 701). At the same time, these unique characteristics of reading on screen may possibly hinder reading performance, as they require more attention from readers and demand more of readers' cognitive load (Jeong, 2012). The divided opinions have driven researchers to further compare and explore whether reading on screen may or may not be as effective as reading on paper. Thus far, no consensus has been reached on this issue.

Dillon (1992) considered the possible distinctions between different reading media from an ergonomic perspective. By weighing reading processes (eye movement, manipulation, and navigation) and outcomes (speed, accuracy, fatigue, comprehension, and preference), the author concluded that reading on screen had its limitation, but it was possible to eliminate performance deficit (e.g., slower reading speed) of reading on screen. At the same time, the author maintained that it was insufficient to account for the differences between reading on screen and reading on paper by examining only a single or a few factors. Since Dillon's research, a systematic literature review or a meta-analysis has been absent on the topic, despite the effort researchers made in the past 20 years.

Most related studies in the past two decades were carried out within the participants' native language context. Existing studies have examined learners' performance when they were reading on different media, such as screen and paper. Some researchers found that there were no differences in terms of reading comprehension and reading speed, and this finding was consistent through studies on both reading for academic and non-academic purposes (e.g., Farinosi, Lim, & Roll, 2016; Oborne & Holton, 1988; Porion, Aparicio, Megalakaki, Robert, & Baccino, 2016). For example, in Margolin and colleagues' (2013) study, the researchers divided 90 participants, ages 18 to 25, into three groups. Each group was presented with five expository texts and five narrative texts in the format of paper, computer, or Kindle. After reading each text, the participants were given five or six multiple-choice comprehension questions. By comparing the results, the researchers concluded that there were no significant differences among different reading media in terms of reading comprehension. Based on such findings, Margolin and colleagues claimed that computers and eReaders, such as Kindle, were viable alternatives to the traditional paper medium in terms of reading comprehension.

At the same time, many other researchers found that difference of reading media would lead to a difference in understanding. The majority of researchers in this group discovered that reading on paper was more effective (e.g., Kerr & Symons, 2006; Mangen, Walgermo, & Brønnick, 2013; Rasmusson, 2015; Stoop, Kreutzer, & Kircz, 2013). For example, Ackerman and Lauterman (2012) shed light on how metacognitive regulation would affect undergraduate students' performance when they were reading academic texts on different media. Specifically, they examined learners' test scores across different reading formats. When time pressure was not present, there were no significant differences between reading on computer and reading on paper. However, under time pressure, learners performed better when they were reading on paper. The researchers then concluded that "computerized study environments generate contextual cues that hinder cognitive processes, while paper tends to facilitate more effective learning" (Ackerman & Lauterman, 2012, p.1826).

ther researchers who claimed there was a difference between reading on screen and reading on paper maintained that reading on screen had its advantages (Moore & Zabrucky, 1995; Öztürk & Horzum, 2013). For example, in a recent study, Sackstein, Spark, and Jenkins (2015) conducted a quasi-experimental study to look at 68 students' use of tablets across multiple South African high schools and universities. In contrast to many previous studies, Sackstein and colleagues found that the majority of their participants read faster on screen while the reading comprehension score did not differ significantly between paper and tablets. Based on the findings, the researchers claimed that reading on screen was "suitable … for reading and learning. And therefore, [it] can be used for academic work" (p. 1).

In order to better understand how reading on screen can be different from reading on paper, researchers have attempted to make clear the possible causes for the differences through inquiring learner's attitudes and perception towards reading on screen (e.g., Liu, 2006; Tveit & Mangen, 2014). For example, Chou (2012) examined the reading behavior and attitudes of five English-as-a-second-language graduate students. By looking at questionnaires, interviews, and observations, Chou discovered that when reading academic texts intensively, the participants preferred to read on paper because they believed that reading on screen limited their use of reading strategies. Similarly, Young (2014) looked at 11 university students' information gathering and reading tasks, and found that participants were inclined to read on paper because they believed that contents from online were “unreliable, inaccurate, difficult to navigate, [and] awkward to read” (p. 390). In contrast, in Connell, Bayliss & Farmer (2012) study, participants displayed a preference for reading on screen as they found reading devices, such as tablets and eReaders, easier to use than the printed materials.

In the current meta-analysis, we looked at relevant studies since 2000 and presented summarized findings on whether reading on screen and reading on paper differ, in terms of reading comprehension and reading speed.

3. Methods

3.1. Search procedures and inclusion criteria

First, we conducted an initial search in the following database: Academic Search Complete, Applied Science & Technology Source, Education Source, ERIC (Education Resource Information Center), LISTA (Library, Information Science & Technology) Abstracts with Full Text, and PsycINFO. The initial search applied the key phrase “reading on screen” along with possible variables for “screen” such as “computer”, “eReader” and “phone”, and focused on academic studies written in English, dating from 2000 to 2016. In total, 416 articles were shown in the list on January 28, 2016, which included 50 dissertations/reports.

We then reviewed the 416 articles based on the following criteria: 1) the study focused on both reading on screen and reading on paper; and 2) the study examined reading on screen and reading on paper from the perspectives of reading comprehension and/or reading speed. For reading comprehension, we looked at studies measuring comprehension test/quiz score (e.g., Ackerman & Lauterman, 2012; Daniel & Woody, 2013). Studies that measured simple recall tasks were excluded because we did not consider recalling as comprehension. For reading speed, we looked at studies measuring reading time (Noyes & Garland, 2003). Type and length of texts being read in the study were not addressed in the current meta-analysis. Future meta-analyses could assess this information. Nineteen studies were identified based on the above-mentioned criteria. From there we conducted a follow-up ancestry search (review references of the found studies) following the same criteria and added nine more studies.

After reviewing the 28 studies, we decided that 17 of them contained sufficient statistical information for calculating the effect size and were suitable for this meta-analysis. A PRISMA Flow Diagram (Moher, Liberati, Tetzlaff, & The PRISMA Group, 2009) was included to show the search procedure (see appendix). Among the final 17 studies, 16 were from academic journals and one was a dissertation (see Table 1 for information such as publication year, country of study, participants, and outcome variables for the 17 studies). We contacted four authors and obtained responses from three of them either for missing statistical information (Ackerman & Lauterman, 2012; Daniel & Woody, 2013) or for information regarding potential moderator analyses (Margolin et al., 2013).

3.2. Reliability of coding

The first and second authors coded the following eight domains for the 17 selected studies separately: Year published, country, gender, grade, sample size, sampling methods (random versus non-random), research design (experimental versus observational), and on-screen media (computer or eBook/eReader). The interrater reliabilities for the eight moderators ranged from 82% (screen type) to 100% (publication year and school level), with the average Cohen's Kappa of 0.95. We then discussed and reached a total agreement before proceeding to data analysis.

3.3. Effect size computation

Meta-analysis is an analysis of analyses that examines a particular topic of interest with the intent to synthesize the findings (Glass, 1976). The value that summarizes the findings is referred to as effect size. Hedges' *g*, a corrected version of Cohen's *d*, was used in this study for the reason that it has been regarded as an unbiased and conservative estimate, compared with Cohen's *d*. With a large sample size, the difference between Cohen's *d* and Hedges' *g* would be negligible. Yet when using small sample size, the difference between the two would be noticeable, as Cohen's *d* is based on the maximum likelihood estimation when calculating the variance, whereas Hedges' *g* is based on Bessel's correction. Since Hedges' *g* allows a meta-analyst to weight two groups' varied standard deviations by their sample sizes, it is advantageous to use for unequal group sample sizes, which is exactly the case in this meta-analysis.

$$\text{Cohen's } d = (M_1 - M_2)/SD_{pooled}$$

$$SD_{pooled} = \sqrt{[(n_1 - 1)SD_1^2 + (n_2 - 1)SD_2^2]}/(n_1 + n_2 - 2)$$

Where M_1 is the mean of treatment group, M_2 the mean of control group, SD_{pooled} the weighted and pooled standard deviation, and n_1 and n_2 the sample size for treatment and control groups respectively.

$$\text{Hedges' } g \cong d\{1 - 3/[4(n_1 + n_2) - 9]\}$$

Table 1
Characteristics of the studies included.

Study	Publication year	Publication type	Country of study	Outcome variables	Screen type	Type of texts, length of texts (average)	School (Age) level
Ackerman & Goldsmith	2011	Journal	Israel	Performance	Computer	Expository, 1000–1200	Post-secondary
Ackerman & Lauterman	2012	Journal	Israel	Test scores; study time	Computer	Expository, 1000–1200	Post-secondary
Baker	2010	Dissertation	U.S.A.	Performance scores	Kindle; iPod Touch	N/A, N/A	Post-secondary
Daniel & Woody	2013	Journal	U.S.A.	Quiz performance; reading time (lab & home conditions)	Computer	Expository, N/A	Post-secondary
Gulbrandsen et al.	2002	Journal	Scandinavia	Sum scores	Computer	Expository, N/A	Job-related
Jeong	2012	Journal	South Korea	Reading comprehension	Computer	Narrative, 700	K-12
Kim and Kim	2013	Journal	U.S.A.	Reading speed and comprehension	Computer	Expository, N/A	K-12
Koepper et al.	2016	Journal	Germany	Reading speed & proofreading performance	Computer	Narrative, 870	Post-secondary
Mangen et al.	2013	Journal	Norway	Reading comprehension and speed	Computer	N/A, 1400–2000	K-12
Margolin et al.	2013	Journal	U.S.A.	Comprehension accuracy	Computer; eReader	Expository, 542; Narrative, 542	Post-secondary
Mayes et al.	2001	Journal	U.S.A.	Reading time & comprehension	Computer	Expository, N/A	Post-secondary
Norman & Furnes	2016	Journal	Norway	Learning outcomes	Computer; iPad; Kindle	Expository, 1000	Post-secondary
Noyes & Garland	2003	Journal	England	Reading time; correct scores; memory	Computer	Expository, 295	Post-secondary
Porion et al.	2016	Journal	France	Comprehension	Computer	Expository, N/A	K-12
Rockinson-Szapkiw et al.	2013	Journal	U.S.A.	Grades and CAP Learning Scale	e-Textbook	N/A, N/A	Post-secondary
Siegenthaler et al.	2011	Journal	Switzerland	Reading speed	iRex; Booken; Sony; ECTACO jetBook	Narrative, N/A	Mixed (16–71)
Wästlund et al.	2005	Journal	Sweden	Reading test scores; scores for adjudged quality; number of headlines derived	Computer	N/A, 1000	Post-secondary

Hedges' g eliminates a small positive bias that may affect the calculation of d (Hedges, 1981). If the effect size is positive for the differences in reading comprehension between reading on screen and reading on paper, this means that reading on screen is better, in terms of reading comprehension. However, as for the differences in reading speed between reading on screen and reading on paper, having a positive effect size signifies that reading on screen is slower than reading on paper.

3.4. Rationale for using RVE meta-analysis

Standard meta-analysis treats all effect sizes as independent even if some stem from the same studies. Effect sizes coming from the same studies tend to share their participants and characteristics either under the conditions of treatment or control, thus making them highly correlated with each other. Traditionally, meta-analysts use either the seemingly representative effect size by implementing specific inclusion criteria or the effect size that averaged several effect sizes from the same studies. Such practices of choosing one effect size or aggregation miss the nuanced picture of summary effect sizes. One way of resolving this problem is to use the variance-covariance structure from the studies that report multiple effect sizes. Yet the variance-covariance structure has rarely been reported in empirical studies. Recently, a few meta-analysts have recommended the robust variance estimation (RVE) meta-analysis model, which does not require the variance-covariance structure (Hedges, Tipton, & Johnson, 2010; Tanner-Smith, Tipton, & Polanin, 2016). Under RVE meta-analysis model, researchers make use of all the effect sizes available from the studies and take into consideration the correlations of effect sizes derived from the same studies. With regard to the use of the number of sample sizes required, Tipton (2013b) developed a small-sample corrections method in relation to the estimators and degree of freedom. We employed her corrections method to overcome the relatively smaller number of primary studies used in our RVE-based meta-analysis and meta-regression.[1]

3.5. Statistical strategies

In this study, robust variance estimation (RVE) meta-analysis models were employed to obtain summary effect size from a number of dependent effect sizes. These were followed by four different RVE meta-regression models to examine the potential effects of some of the covariates (moderators) on the mean differences between reading on screen and reading on paper, in terms of reading comprehension and reading speed. We dichotomized three moderators used for the analysis. We collapsed year of publication into two levels with the cut-off year of 2013 based on the equal percentile. As for the country of study, we used the United States versus others. Finally, types of on-screen media were composed of computer versus others (eBook, etc.). In the current meta-analysis, we only looked at computer versus other screen types for exploratory purposes. Future meta-analyses could further divide screen types.

Certain potential candidates for moderators, such as gender, grade, sample size, sampling methods, and research design, were not included because they did not satisfy the requirements of running RVE meta-regression models (e.g., some potential moderators had an excessively imbalanced number of sub-groups).

Prior to proceeding with summary effects and moderator effects, there is a brief discussion of detecting and how to deal with outlier effect sizes and potential publication bias in this study. R package 'robumeta' was used for RVE meta-analysis models and for robust variance meta-regression (R Core Team, 2013). Tests for statistical significance was set at the 0.05 level throughout the analysis.

4. Results

4.1. Overall characteristics

Seventeen studies were selected in this meta-analysis, with 47 and 19 effect sizes for reading comprehension and reading speed respectively. Out of 17 studies, nine studies were conducted before 2013. Sixteen studies were peer-reviewed, and one was not (dissertation). Six studies were conducted in the United States, four in Scandinavian countries, four in the rest of Europe, two in Israel, and one in South Korea. Computer was used as a screen type for 14 studies, and portable reading devices, such as Kindle, were used in five studies. Eleven studies focused on post-secondary school students, four studies focused on K-12 school students, one study looked at job-level participants, and one study looked at mixed-age participants. Regarding the types of texts, ten studies used expository texts, three used narrative texts, and the type of texts for the other four studies were not specified. The length of these texts, if reported, ranged from about 300 to 2000 words, with most of the studies used texts whose length was about 1000 words. Total sample size was 4831 for reading comprehension and 1359 for reading speed.

In relation to the outliers of the distribution of effects, the study of Kim and Kim (2013) seemed to be a potential outlier when considering effect size estimates and confidence intervals (CIs). However, we decided to retain the study in order not to lose information.

4.2. Publication bias

Research has shown that the studies with significant findings, large effects, or large sample size were more likely to be published than those with non-significant findings, small effects, or small sample size (Borenstein, Hedges, Higgins, & Rothstein, 2009; Dickersin, 2005; Hedges, 1989). This is referred to as publication bias in meta-analysis. The bias is also related to the existence of

[1] The coding used for small-sample corrections was as in the following: robu(formula = d ~ 1, data = comprehension, studynums = study, var.eff.size = v, rho = 0.80, small = TRUE) (Fisher, Tipton, & Zhipeng, 2017).

Table 2a
Fail-safe N calculations for reading comprehension.

	Rosenthal (1979)	Orwin (1983)	Rosenberg (2005)
Observed significance level	< 0.0001		0.0103
Average effect size		−0.15	−0.08
Target significance level	0.05		0.05
Target effect size		−0.08	
Fail-safe N	188	47	34

Table 2b
Fail-safe N calculations for reading speed.

	Rosenthal (1979)	Orwin (1983)	Rosenberg (2005)
Observed significance level	< 0.0001		< 0.0001
Average effect size		0.34	0.43
Target significance level	0.05		0.05
Target effect size		0.17	
Fail-safe N	271	19	267

missing studies that escaped researchers' inclusion criteria through either electronic or ancestry searches. Likewise, as evidenced by Rothstein, Sutton, and Borenstein's (2005) review, published studies were more likely to be included in the meta-analysis. This is problematic in that the studies in such meta-analyses yield biased estimates of effect size due to the use of biased samples. In order to tackle this issue, we generated funnel plots and conducted Egger, Smith, Schneider, and Minder's (1997) regression tests for funnel plot asymmetry to examine the relationship between sample size and effect size (Figures not shown here). Results did not identify publication bias for both reading comprehension ($z = -1.26$, $p = .21$) and reading speed ($z = -0.75$, $p = .45$). Furthermore, our *fail-safe N* tests based on Orwin's (1983) approach consolidated the robustness of observed summary effect sizes in our study (See Tables 2a and 2b). Given the preliminary findings regarding the presence of publication bias, we could proceed with the computation and analyses of summary effects and moderator effects.

4.3. Summary effects

The effect sizes for reading comprehension and reading speed were reported separately. For example, within a common scale, a positive value might indicate that reading on paper is better in terms of reading comprehension (higher comprehension score), but the same positive value might indicate that reading on paper is worse in terms of reading speed (longer time). In the forest plots (see Fig. 1a and b), the dotted line in the middle represents the line of no effect, which has the value of a zero, whereas the boxes and their size indicate the effect estimates and the weighting of the studies respectively. The lines horizontally dissecting the boxes represent the CIs, with the shorter lines indicating narrower CIs and higher accuracy of the study. The open diamond in the last row indicates the overall results of our meta-analysis, with its middle part representing the value for the summary effect estimate and its width the range of the overall CIs.

4.3.1. Mean differences in comprehension between reading on screen and reading on paper

Since there were several correlated effect sizes obtained from each study, namely 47 effect sizes out of 17 studies, it was necessary to take into consideration the correlations between the effect sizes stemming from the same studies. The default correlation between the effect sizes within the same studies was set to 0.80,[2] based on the assumptions of the presence of strong correlations among the effect sizes from the same studies. In this regard, the random variance estimation (RVE) meta-analysis was needed. As shown in Table 4, RVE meta-analysis indicated that the mean difference in reading comprehension between reading on screen and reading on paper was −0.21 with a 95% CI of (−0.38, −0.03), $p = .02$, meaning that readers had significantly higher comprehension scores when reading on paper than reading on screen. Fig. 1a showed the RVE-based forest plot related to the standardized mean differences in reading comprehension between reading on screen and reading on paper. Here the open diamond does not cross the line of no effect, which also confirmed statistically significant findings in favor of reading on paper. The boxes and their horizontal lines denoting CIs from the plot show that there are medium to high levels of between-study heterogeneity ($\tau^2 = 0.11$, $I^2 = 73.23\%$). Unlike the weight in standard meta-analysis, the weight in RVE-based forest plot was not truly proportional to the effect size variance or confidence intervals, since the combined study weight was divided evenly across the study effect sizes.

4.3.2. Mean differences in reading speed between reading on screen and reading on paper

In the same logic used in reading comprehension, RVE meta-analysis was conducted to take into account correlated effect sizes, which is 19 effect sizes out of eight studies in relation to reading speed. The correlation of 0.80 was used throughout due to the assumed

[2] We replicated the results by varying degrees of correlations (e.g., 0, 0.20, 0.40, 0.60, 0.80, and 1.00) as part of sensitivity analysis. As shown in Tables 3a and 3b, the findings were robust.

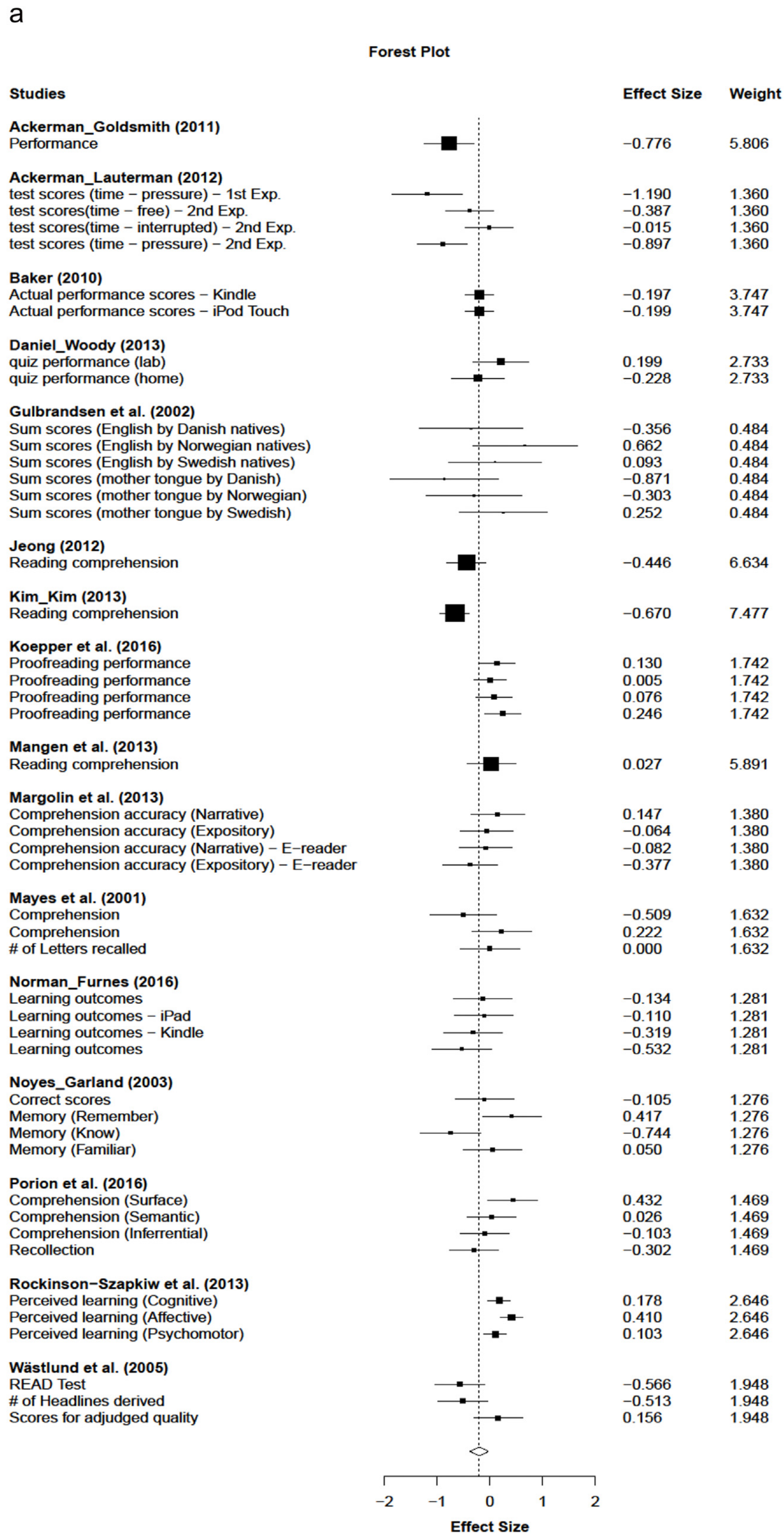

Fig. 1a. Forest plot: comprehension between reading on screen and reading on paper.

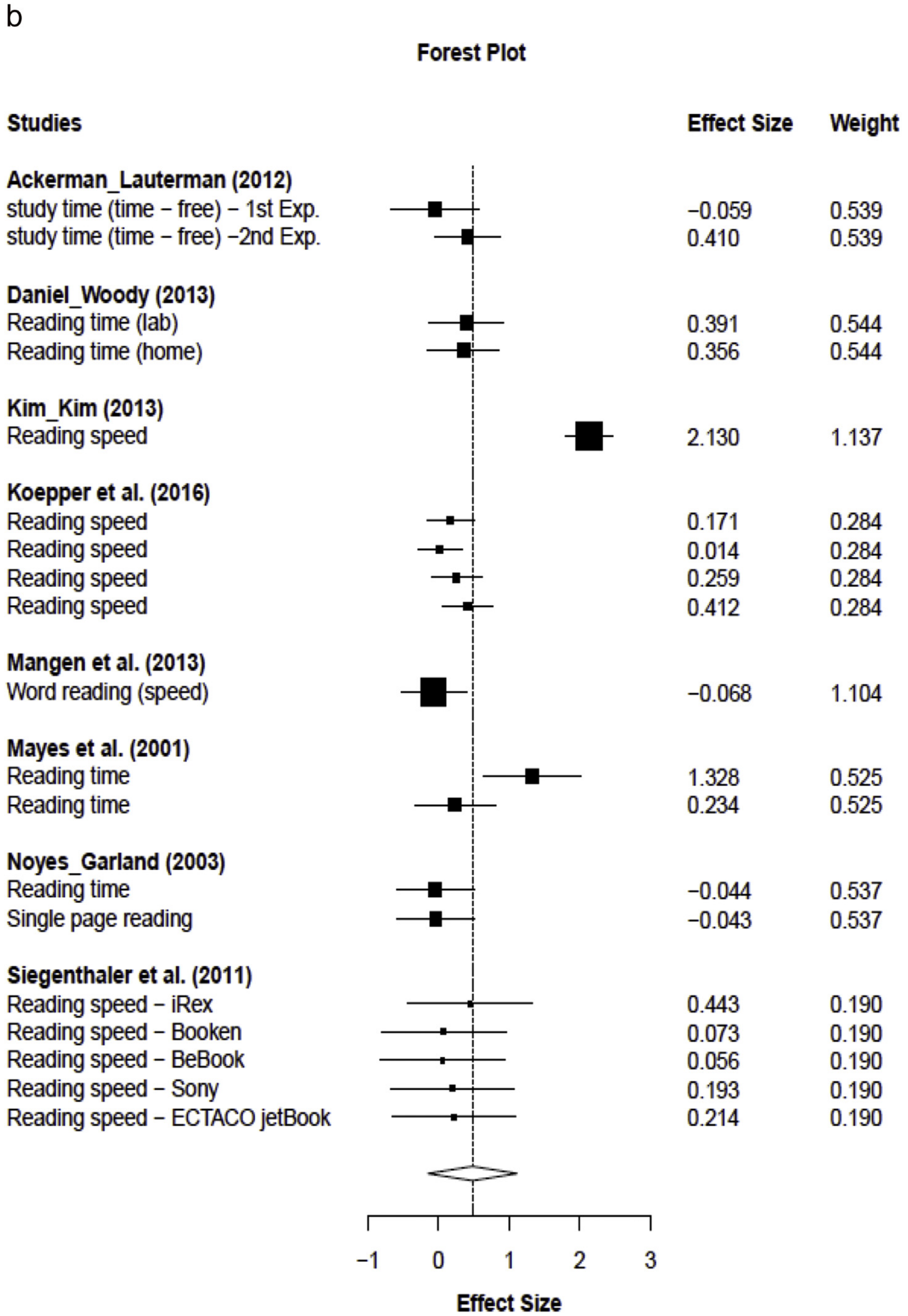

Fig. 1b. Forest plot: reading speed between reading on screen and reading on paper.

presence of strong correlations among dependent effect sizes. The results of RVE meta-analysis revealed that the mean difference in reading speed between reading on screen and reading on paper was 0.48 with a 95% *CI* of (−0.15, 1.11), $p = .11$, (see Table 4), indicating that there were no differences in terms of reading speed between reading on screen and reading on paper. The RVE-based forest plot related to the standardized mean differences in reading speed between reading on screen and reading on paper confirmed this finding (see Fig. 1b). The summary effect size could also be found at the bottom of the plot as an open diamond shape, which was located on the right side of zero (no effect), with part of its confidence interval hugging the no-effect zone. The boxes and their horizontal lines denoting CIs from the plot show that there are high levels of between-study heterogeneity ($\tau^2 = 0.85$, $I^2 = 93.36\%$).

Despite the presence of medium to high levels of heterogeneity in RVE-based meta-analysis as shown above, we further proceeded with RVE-based meta-regression analyses for the following reasons. First, the purpose of RVE-based meta-analysis was to rectify standard errors while focusing on the estimation of fixed effects, such as the measures of summary effect size and meta-regression

Table 3a
Sensitivity Analysis on the RVE meta-regression: Reading Comprehension.

	Rho = 0		Rho = 0.20		Rho = 0.40		Rho = 0.60		Rho = 0.80		Rho = 1.00	
	b	se	b	se	b	se	b	se	b	se	b	se
Intercept	−0.44	0.24	−0.44	0.24	−0.43	0.23	−0.43	0.23	−0.43	0.23	−0.43	0.23
Year	0.26	0.14	0.26	0.14	0.26	0.14	0.26	0.14	0.26	0.14	0.26	0.14
Country	0.07	0.24	0.06	0.24	0.06	0.24	0.06	0.24	0.06	0.24	0.06	0.24
Type	0.23	0.25	0.22	0.25	0.22	0.25	0.22	0.24	0.22	0.24	0.22	0.24
τ^2	0.09		0.09		0.09		0.09		0.09		0.10	

Table 3b
Sensitivity Analysis on the RVE meta-regression: Reading Speed.

	Rho = 0		Rho = 0.20		Rho = 0.40		Rho = 0.60		Rho = 0.80		Rho = 1.00	
	b	se	b	se	b	se	b	se	b	se	b	se
Intercept	0.99	0.40	0.99	0.40	0.99	0.40	0.99	0.40	0.99	0.40	0.99	0.40
Year	0.20	0.36	0.20	0.36	0.20	0.36	0.20	0.36	0.20	0.36	0.20	0.36
Country	−1.02	0.53	−1.02	0.53	−1.02	0.53	−1.02	0.53	−1.02	0.53	−1.02	0.53
Type	0.23	0.21	0.23	0.21	0.23	0.21	0.23	0.21	0.23	0.21	0.23	0.21
τ^2	0.48		0.49		0.49		0.50		0.51		0.51	

Table 4
Findings of RVE meta-analysis related to reading comprehension and reading speed.

	Reading Comprehension	Reading Speed
Hedges' g (effect size)	−0.21	0.48
SEg	0.08	0.27
95% CI	[−0.38, −0.03]	[−0.15, 1.11]
Tau-square	0.11	0.85
N	47	19
K	16	8
p	0.02	0.11
rho	0.80	0.80

Notes: N = Number of effect sizes; K = Number of studies; rho = correlation.

coefficients, but not to model variation. Second, the between-study heterogeneity measured in RVE-based meta-analysis was obtained through method-of-moments with assumed covariance structures, which were a lot simpler than actual covariance structures in actual data (Scammacca, Roberts, & Stuebing, 2014; Tanner-Smith & Lipsey, 2015; Tanner-Smith & Tipton, 2014).

4.4. Moderator effects

4.4.1. Reading comprehension

In order to examine whether there were any moderation effects on the relationship between reading comprehension and types of media, we ran RVE meta-regression models. Specifically, we regressed effect sizes on three potential moderators: year of publication, country of study, and types of screen media. As shown in model 3 of Table 5a, none of the potential moderators turned out to be significant at the 0.05 level. Namely, the summary effect sizes in reading comprehension between reading on screen and reading on paper remained the same, regardless of publication year, country of study, and types of on-screen media.

4.4.2. Reading speed

We also conducted an RVE meta-regression, regressing effect sizes of reading speed on three potential moderators, such as year of publication, country of study, and types of on-screen media. We dichotomized the moderators in the same way that we dichotomized the moderators for reading comprehension. As shown in Table 5b, none of them had a significant moderation effect on the relationship between reading speed and types of media.

5. Discussion and conclusion

Results of RVE meta-analysis showed that reading on paper was better than reading on screen in terms of reading comprehension. When it comes to reading speed, the RVE meta-analysis shows that there is no significant difference between reading on screen and reading on paper. Quite possibly, the advantage of reading on paper could be accounted for by readers' extensive experience of

Table 5a
Reading Comprehension Effect Size Regressed on Year (Collapsed), Country, and Type (n = 47, k = 16).

	Model 1 (Year)				Model 2 (Year & Country)				Model 3 (Year, Country & Type)			
	b	95% CI	df	p	b	95% CI	df	p	b	95% CI	df	p
Intercept	0.35	[−0.57, −0.13]	6.58	.01	−0.32	[−0.69, 0.04]	4.42	.07	−0.43	[−1.03, 0.16]	5.13	.12
Year	0.27	[−0.05, 0.59]	13.29	.10	0.26	[−0.04, 0.56]	9.65	.09	0.26	[−0.05, 0.57]	9.20	.09
Country					−0.04	[−0.40, 0.32]	8.54	.83	0.06	[−0.52, 0.65]	5.85	.80
Type									0.22	[−0.42, 0.86]	4.78	.41
Residual τ^2		0.11				0.12				0.10		

Notes: 1) *p < .05; **p < .01; ***p < .001.
2) In case that degree of freedom is less than 4, the results should not be trusted.
3) n is number of effect sizes; k is number of studies; and rho of 0.80 was used throughout the RVE meta-regression.

reading on paper, which shapes their preference for reading on paper and strengthened their use of reading on paper strategies. At the same time, as mentioned earlier, an increased demand in cognitive load when reading on screen (unfamiliarity with reading devices, specific strategies for reading on screen, etc.) could also impede readers' comprehension when reading on screen (Ackerman & Lauterman, 2012). Interestingly, our results showed reading speed on paper or on screen was not affected by increased cognitive load. Since the current meta-analysis contains a small sample size for reading speed, we encourage future meta-analyses to include more studies to see if the results remain the same.

None of the potential moderators was significant at the 0.05 level. In the meantime, albeit not significant, examination of the p-value for the difference tests prior to 2013 and after 2013 respectively ($p = .10$) indicates that the magnitude of the difference in reading comprehension between paper and screen follows a diminishing trajectory. While we cannot make a claim directly based on this, it is meaningful in the way that it provides directions for future meta-analyses on the same topic. As more and more researchers have examined reading on screen in recent years, the latest studies in the field since the date of our search should be added to the pool of analysis, which might yield a different result.

Besides, moderators not presented in the current meta-analysis could be included in future meta-analyses. As an example, over the years, researchers have looked at different factors that could influence readers' performance when reading on screen. A number of studies have claimed that certain fonts worked better on screen than others. For example, the font Verdana was believed to be a better choice across multiple studies (Ali, Wahid, Samsudin, & Idris, 2013; Chaparro, Shaikh, Chaparro, & Merkle, 2010; Hojjati & Muniandy, 2014). Some researchers claimed that spacing had an impact on reading performance. For example, Dyson (2004) found that readers performed better when the texts were presented using double-space on screen. Contrastively, Ni, Branch, Chen, and Clinton (2009) concluded from their study that spacing did not significantly influence reading performance. Instead, they argued that on-screen reading performance was affected by psychological factors such as age and reading strategy. It will be interesting to, if possible, include studies that examine font and spacing, as well as psychological factors, in future meta-analyses, and see how they will affect reading performance in terms of reading comprehension and reading speed.

Future meta-analyses could also closely look at other potential variables, such as age and gender, which, in some researchers' opinions, could affect students' online learning (Hoskins & Van Hooff, 2005; Muilenburg & Berge, 2005). In the current meta-analysis, most focal studies (11 out of 17) examined college students. The result might be different if more studies involving younger or older participants were included. Gender information was not easy to obtain in the current meta-analysis. In future meta-analyses, if possible, information on gender ratio for treatment and control group may be gleaned for analysis.

With regard to publication bias, funnel plots gave us mixed results. However, considering the subjectivity of funnel plots, we also conducted both regression tests for funnel plot asymmetry and *fail-safe N* tests. The regression test showed us there was no publication bias. The *fail-safe N* tests showed that 47 more studies for reading comprehension and 19 more for reading speed would be needed to reduce possible publication bias. *Fail-safe N*'s were relatively higher when comparing with the 16 and eight studies used for reading comprehension and reading speed respectively in our meta-analysis, which led us to conclude that there was a higher

Table 5b
Reading Speed Effect Size Regressed on Year (Collapsed), Country, and Type (n = 19, k = 8).

	Model 1 (Year)				Model 2 (Year & Country)				Model 3 (Year, Country & Type)			
	b	95% CI	df	p	b	95% CI	df	p	b	95% CI	df	p
Intercept	0.28	[−0.30, 0.85]	2.99	.22	1.02	[−0.55, 2.59]	2.37	.12	0.99	[−0.60, 2.58]	2.16	.12
Year	0.39	[−0.92, 1.71]	5.98	.49	0.16	[−0.77, 1.09]	3.94	.66	0.20	[−0.87, 1.28]	3.44	.61
Country					−0.10	[−2.54, 0.55]	3.39	.14	−1.02	[−2.59, 0.54]	3.47	.14
Type									0.23	[−0.69, 1.14]	1.96	.39
Residual τ^2		0.896				0.460				0.51		

Notes: 1) *p < .05; **p < .01; ***p < .001.
2) In case that degree of freedom is less than 4, the results should not be trusted. The degrees of freedom for the moderators shown in Models 2 and 3 are less than 4.
3) n is number of effect sizes; k is number of studies; and rho of 0.80 was used throughout.

likelihood of no publication bias.

Despite the debate, the age of digital reading is inevitably coming. Deeper understandings about reading on screen will enable scientists to design better products, and allow educators to help students become more prepared to reading on screen through various approaches, such as introducing specific strategies for reading on screen. This cannot be achieved without the contribution of more related research and meta-analyses in this field.

6. Limitations

As for the use of moderators, our decision to dichotomize publication year based on the equal percentile was somewhat arbitrary and should be based on more meaningful criteria, such as a breakthrough in people's use of computer or Internet for their reading or any noticeable changes in people's habit of reading on screen and/or reading on paper. Likewise, albeit exploratory in nature, we also need a better rationale for our decision to classify the studies conducted in the U.S. versus those from other countries.

Meanwhile, this study does not shed light on potential moderators, such as experimental design (experimental versus non-experimental) and gender (male versus female) in both treatment and control conditions, due to the imbalance in the number of sample sizes between the sub-groups generated. Future studies could examine these moderators to see if they play a role in the relationship between readers' performance and types of media.

As a pilot study, the current meta-analysis only includes studies after 2000 as we only intend to showcase the most recent research when it comes to reading on screen. The future meta-analyses could include studies before 2000 and after 2016 to provide a more comprehensive view.

In terms of RVE meta-regression regarding reading speed, there should be more studies along with more effect sizes in future studies. The number of studies ($N = 8$) in this meta-analysis is relatively small, compared with what has been recommended: Larger than 10 (Higgins & Green, 2011); at least 40 (Hedges et al., 2010; Tipton, 2013a). Although we used Tipton's (2013b) small sample adjustments for our current analysis, it would be meaningful to compare our results with those without small sample adjustments in future studies.

Appendix. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.compedu.2018.05.005.

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