RESEARCH

A Meta-Analysis of the Effect of Paper Versus Digital Reading on Reading Comprehension in Health Professional Education

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Objective. Despite a rise in the use of digital education in health professional education (HPE), little is known about the comparative effectiveness of paper-based reading and its digital alternative on reading comprehension. The objectives of this study were to identify, appraise, and synthesize the evidence regarding the effect of how media is read on reading comprehension in the context of HPE.

Methods. Observational, quasi-experimental, and experimental studies published before April 16, 2021, were included if they compared the effectiveness of paper-based vs digital-based reading on reading comprehension among HPE students, trainees, and residents. Random-effects meta-analyses were performed using standardized mean differences.

Results. From a pool of 2,208 references, we identified and included 10 controlled studies that had collectively enrolled 817 participants. Meta-analyses revealed a slight but nonsignificant advantage to students reading paper-based HPE texts rather than digital text (standardized mean difference, -0.08; 95% CI -0.28 to 0.12). Subgroup analyses revealed that students reading HPE-related texts had better reading comprehension when reading text on paper rather than digitally (SMD = -0.36; 95% CI -0.69 to -0.03). Heterogeneity was low in all analyses. The quality of evidence was low because of risks of bias across studies.

Summary. Current evidence suggests little to no difference in students' comprehension when reading HPE texts on paper vs digitally. However, we observed effects favoring reading paper-based texts when texts relevant to the students' professional discipline were considered. Rigorous studies are needed to confirm this finding and to evaluate new means of boosting reading comprehension among students in HPE programs.

Keywords: evidence synthesis, literature review, e-learning, reading material, health care education

INTRODUCTION

Digital education has become ubiquitous in health professional education (HPE).[1-3] It can be defined as "the act of teaching and learning by means of digital technologies."[1] Digital education encompasses various teaching and learning approaches, ranging from the simple transformation of text from paper-based to digital formats (eg, portable document format) to the interactive use of sophisticated digital technologies.[1] A majority of health professional students and practitioners report using a digital device in their studies or routine clinical practice.[4,5] Despite the rise of digital education, little is known about the comparative effectiveness of reading media, ie, paper-based reading vs its digital alternative, on reading comprehension in HPE.[6,7]

Reading comprehension is a complex process that involves the ability to recall, understand, integrate, and

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evaluate text, and depends on several factors, including the reader (eg, vocabulary, degree of familiarity with the text), the reading content (eg, degree of complexity), and the reading media (see Table 1 for definitions).[8,9] Reviews investigating the impact of reading media on reading comprehension have yielded inconsistent results but tend to favor paper-based reading for comprehension and retention of information.[9-14] Proposed explanations for lower digital-based reading results include readers' variable experience with technology, overconfidence in comprehension, and more superficial reading when using technology.[15,16] Furthermore, the physical presence of a paper text may facilitate reading comprehension and learning.[17]

Previous reviews have not examined the impact of reading media in the context of HPE, an exercise that is of both clinical, disciplinary, and cross-disciplinary interest. From a clinical standpoint, reading comprehension is essential to acquire the knowledge base for effective clinical decision-making that is required for the provision of safe, quality care.[18,19] Health professional education often follows a similar, cross-disciplinary learning framework: a pre-clinical phase characterized by basic science education and a clinical phase integrating prior knowledge and applying it to cases in a clinical context. In all health professions, learners are driven by clinical considerations and a patient-centered perspective influencing their collection and processing of information and consequent decision-making. Examining reading comprehension in the context of HPE may eventually allow drawing inferences between reading comprehension and clinical outcomes.

From a disciplinary standpoint, tenets of disciplinary literacy suggest that the cognitive requirements for reading are intertwined with the specialized knowledge of those who produce and communicate knowledge within each discipline.[20] This is in opposition to the view that reading builds on a generic set of skills and strategies, regardless of the discipline.[21] While the effect of text genre on reading comprehension was considered in previous reviews, they did not examine whether the topic of the text was related to students' discipline.[9,10] Providing students with texts relevant to their discipline may aid their reading comprehension by building on prior knowledge and disciplinary habits of mind (eg, ways of thinking, reasoning, and critiquing).[1] A key learning principle is relevancy; thus, students who deem a text less relevant could have a less meaningful learning experience.[22] Thus, we believe differentiating between texts that are HPE-related and those that are not is fundamental.

Finally, from a cross-disciplinary standpoint, we believe that examining reading comprehension in HPE specifically also provides important insights for other fields of study. The current review will provide a new framework for examining reading comprehension in specific populations, a variable not explicitly controlled for in previous systematic reviews. This is important not only for providing meaningful material to learners, but also in terms of systematic review methodology as a way of reducing potential population and intervention heterogeneity. Thus, this systematic review and meta-analysis builds on previous evidence by considering studies in which the effectiveness of reading media on reading comprehension was evaluated in the context of HPE, examining the effect of text topics (HPE-related or non-HPE-related topics) considering students' professional discipline, and including studies with graduate students. Our objective was to identify, appraise, and describe studies comparing the effectiveness of paper-based versus

Table 1. Definitions of Key Terms Used in a Review and Meta-Analysis of the Effect of Paper vs Digital Reading in Health Professional Education

Terms	Definition
Digital education	An umbrella term encompassing all the learning activities conducted through the use of information and communication technology.
Reading content	The subject/materials provided to the learner which he is expected to read.
Reading media	Platform used for the purpose of reading, which could be either digital or paper-based.
Digital-based	This encompasses the use of any digital device to display the reading content in a given digital format.
Digital device	Digital devices include desktop computers, laptops, tablets, smartphones and e-readers.
Digital format	Digital format refers to the type of document (eg, PDF, Word, HTML) within the digital device.
Text navigation	Text navigation features are contingent on the digital device and format. Examples include scrolling, page flipping, the use of a mouse, and the use of arrows.
Paper-based	This encompasses the use of any paper format to present the reading content.
Paper format	Paper format refers to any type of printed text (eg, books, printed articles, and newspapers).

digital-based reading on reading comprehension among students, trainees, and residents in HPE.

METHODS

This systematic review and meta-analysis was conducted following the Joanna Briggs Institute guidelines.[23] This paper is reported according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines and the PRISMA-S guidelines for reporting literature searches.[24,25] The protocol has been published and registered in the International Prospective Register of Systematic Reviews on April 28, 2020 (PROSPERO; CRD42020154519).[26,27]

This review considered observational, quasi-experimental, and experimental studies published in any language that compared the effectiveness of paper-based vs digital-based reading on reading comprehension. We defined reading comprehension as the immediate recall or understanding of the textual content among HPE students, trainees, and residents. We excluded studies conducted with individuals with reading difficulties, cognitive impairments, and related disorders. Paper-based reading was defined as reading text printed on paper (eg, books, articles). Digital reading was defined as "reading text on digital screens, including computers, tablets, mobile phones, and e-readers."[10] Studies examining media that included videos, animations, hyperlinks, web navigation, gamification, and adaptivity were excluded because these features could confound the results.[10]

The search strategy was designed to focus on three concepts: students, trainees, and residents participating in HPE (population); reading media (intervention); and reading comprehension (outcome). The search strategies for all databases are presented in Appendix 2. We performed searches in six databases (CINAHL via EbscoHost, EMBASE via OVID, ERIC via ProQuest, Medline via OVID, PsychInfo via EbscoHost, and Web of Science) on April 16 and 17, 2020.

Identified citations were uploaded in the Covidence software (Veritas Health Innovation, Melbourne, Australia; www.covidence.org). Duplicates were removed using Covidence. Two independent authors screened studies and reviewed full texts. Disagreements were resolved through discussion.

We worked independently and in duplicate to assess study quality using the Medical Education Research Study Quality Instrument (MERSQI).[28] We also assessed risks of bias independently using the Effective Practice and Organization of Care (EPOC) risk of bias criteria.[29] Risks of bias refer to methodological elements that could affect the internal validity of study results.

We used Covidence to perform data extraction independently and in duplicate. We extracted data at four levels: study level, participant level, intervention level, and outcome level. Data items extracted are specified in the published protocol.[26] In addition, we have added variables related to the context of intervention implementation, including the degree of distraction (low, medium, or high) and presence of supervision (yes, no). We considered the degree of distraction: low, when reading and assessment of reading comprehension had been conducted in a supervised setting without evident mention of potential distractors; medium, when these had been conducted in a supervised setting with possible distractors (eg, multiple testing stations); and high, when these had been conducted in an unsupervised setting (eg, home) with an uncontrollable and unspecified degree of distraction.

The characteristics of studies and interventions were synthesized in a table. We undertook random-effects meta-analyses in Review Manager (RevMan) software, version 5.3 (The Cochrane Collaboration, The Nordic Cochrane Centre, Copenhagen, Denmark, 2014) to compare the effects of paper vs digital reading on reading comprehension in HPE. Data were analyzed using standardized mean differences (SMDs) with 95% confidence intervals (CIs). Heterogeneity was assessed by examining the characteristics of the studies and using the I^2 statistic. Three subgroup analyses were carried out to investigate the impact of moderators on statistical heterogeneity: HPE-related texts; reading time frame, presence of supervision. The risk of reporting bias was assessed qualitatively based on the country of study conduct, the year of study publication, and the statistical significance of study results.

We worked independently to assess the quality of evidence, or our confidence, in the pooled SMDs. We used the Grading of Recommendations Assessment, Development and Evaluation web-based software (GRADEpro, 2015, McMaster University and Evidence Prime, Inc, https://gradepro.org). We considered five factors for assessing the quality of evidence (risk of bias, indirectness of evidence, unexplained heterogeneity or inconsistency of results, imprecision of the results, probability of reporting bias).

RESULTS

From a pool of 2,208 potentially relevant articles, we found 10 quantitative, controlled studies comparing the effects of paper and digital reading on reading

comprehension in HPE. Eight studies were included in the meta-analysis because they provided enough data to calculate SMD (Figure 1).

Selected characteristics of the studies included are summarized in Table 2. Nine studies were randomized controlled trials and one was a non-randomized controlled trial. Participants were undergraduate psychology students (n = 5),[6,7,30-32] undergraduate dental students (n = 2),[33] graduate medical students (n = 2),[34,35] and graduate optometry students (n = 1), all of which were considered to be students in HPE.[36-39] Studies involving graduate students, including medical and optometry students, accounted for three of the 10 studies included. The median sample size was 70 participants. All included studies were deemed of moderate quality according to the MERSQI; scores ranged from 10.5 to 12.5 out of 18 possible points.

Key characteristics of paper-based and digital-based reading media are summarized in Table 2. Reading topics varied greatly, ranging from oral histology to microeconomics. Whereas all studies included health professional students, the topic of texts was related to HPE in four studies, non-related to HPE in five studies, and not specified in one study. We observed significant variations regarding text length. The reading time was unlimited in five studies, limited to five to 25 minutes in four studies, and not specified in one study. In a majority of studies, students' reading was supervised in a controlled setting (n = 7), which meant that there was a low or medium potential for distraction. In the three remaining studies, students read at home and were not supervised, suggesting a high potential for distraction.

All studies were judged to be at high risk of bias. The risk of selection bias was high or unclear in all studies, as was the risk of bias related to imbalances between groups in characteristics of participants at baseline. The risk of bias related to imbalances between groups in outcome measurements at baseline were high or unclear in eight studies.[6,7,30-32,34-36] Six studies had a high or unclear risk of attrition bias.[6,30-32,34,35] Six studies had a high or unclear risk of performance bias.[6,7,32,34-36] Six studies had a high or unclear risk of contamination bias.[6,30,32,34-36] Finally, the risk of reporting bias was low in all but one study.[34]

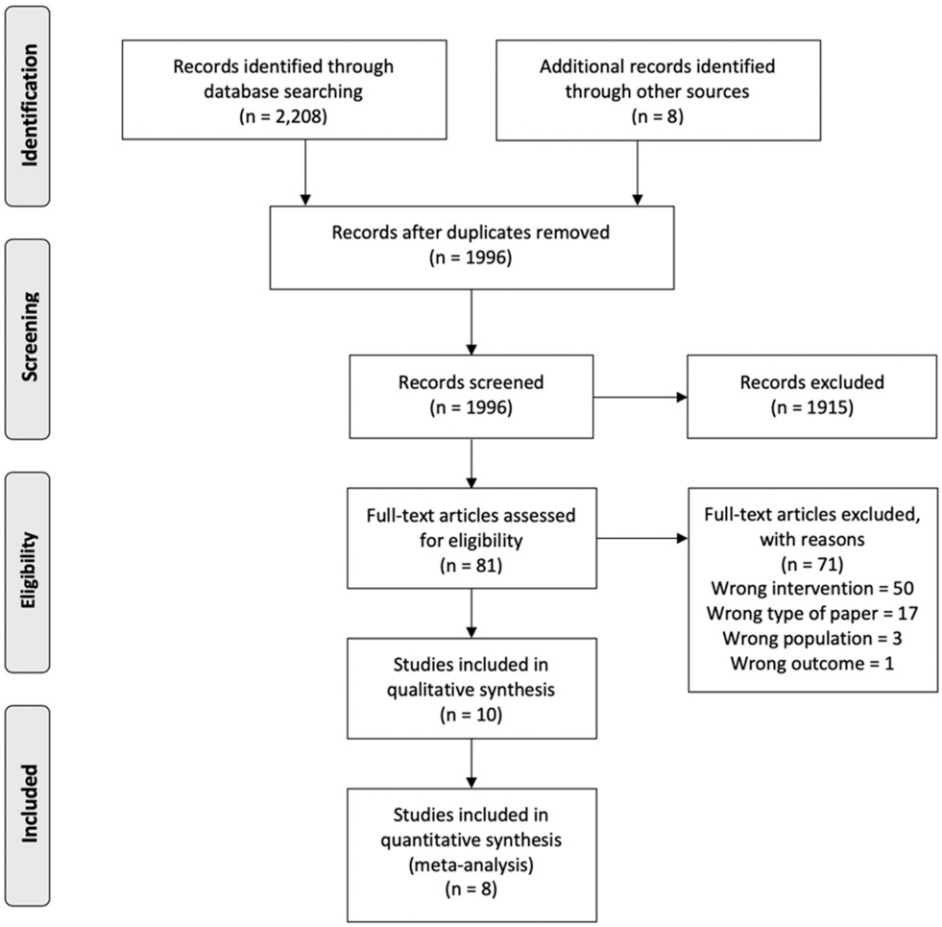

Figure 1. Flow Diagram of Article Screening and Selection

Table 2. Characteristics of Included Studies

Author, Year, Country	Study Design	Study Participants	MERSQI Score[b]	Intervention (Reading Media)	Format	Text Navigation	Reading Content	Text Length	Reading Time Frame	Degree of Distraction	Presence of Supervision
Mayes (2001) USA	RCT	Undergraduate psychology students N = 48	11.5	Paper reading	Article	Page flipping	American Scientist article "Designed to Fail"	2 pages	Limited; 25 minutes	Medium	Yes; room with multiple testing stations
				Digital reading; desktop computer	PDF	NR	American Scientist article "Designed to Fail"	2 pages	Limited; 25 minutes	Medium	Yes; room with multiple testing stations
Green (2010) USA	RCT	Undergraduate psychology students N = 82	11	Paper reading	Article	Page flipping	Meteorology and enology	2 pages	Limited; 5 minutes	Low	Yes; individual testing room
				Digital reading; desktop computer	PDF	Computer mouse	Meteorology and enology	2 pages	Limited; 5 minutes	Low	Yes; individual testing room
Taylor (2011) USA	RCT	Undergraduate psychology students N = 74	10.5	Paper reading	Paperbound text	Page flipping	Microeconomics	49 pages	Unlimited	Low	Yes; individual testing room
				Digital reading	NR	NR	Microeconomics	49 pages	Unlimited	Low	Yes; individual testing room
Matthes (2012) Germany	RCT	Medical students N = 269	11.5	Paper reading	Printed text	NR	Basic medical pharmacology	NR	NR	High	No; NR
				Digital reading; desktop computer	PDF	NR	Basic medical pharmacology	NR	NR	High	No; NR
Ramseier (2012a) Switzerland	NRCT	Undergraduate dental students N = 35	10.5	Paper reading	Text on paper	Page flipping	Oral histology	43 pages, 6 chapters	Unlimited	High	No; at home
				Digital reading; desktop computer	HTML	Page flipping using arrows on computer screen	Oral histology	43 pages, 6 chapters	Unlimited	High	No; at home
Ramseier (2012b) Switzerland	RCT	Undergraduate dental students N = 32	11.5	Paper reading	Text on paper	Page flipping	Oral histology	43 pages, 6 chapters	Unlimited	High	No; at home
				Digital reading; Desktop computer	HTML	Page flipping using arrows on computer screen	Oral histology	43 pages, 6 chapters	Unlimited	High	No; at home

(*Continued*)

Table 2. (*Continued*)

Author, Year, Country	Study Design	Study Participants	MERSQI Score[b]	Intervention (Reading Media)	Format	Text Navigation	Reading Content	Text Length	Reading Time Frame	Degree of Distraction	Presence of Supervision
Margolin (2013) USA	RCT	Undergraduate psychology students N = 90	12.5	Paper reading	Printed text	NR	NR	1084 words	Unlimited	Low	Yes; office space
				Digital reading; desktop computer or Kindle	PDF (for desktop computer)	Scrolling with a computer mouse or computer arrow keys	NR	1084 words	Unlimited	Low	Yes; office space
Seehafer (2014) USA	RCT	Undergraduate psychology students N = 67	11.5	Paper reading	Text on paper	NR	Fiction short story	706 words	Unlimited	Low	Yes; NR
				Digital reading; desktop computer	NR	NR	Fiction short story	706 words	Unlimited	Low	Yes; NR
Ramalingam (2018) Malaysia	RCT	Medical students N = 80	12.5	Paper reading	Text on paper	NR	Fiction short story	NR	Limited; 10 minutes	Low	Yes; conducive environment
				Digital reading; laptop computer	NR	NR	Fiction short story	NR	Limited; 10 minutes	Low	Yes; conducive environment
McDowell (2019) USA	RCT	Optometry students N = 40	12	Paper reading	Text on paper	NR	Optometry	NR	Limited; 15 minutes	Low	Yes; NR
				Digital reading; desktop computer	Word documents	NR	Optometry	NR	Limited; 15 minutes	Low	Yes; NR

Abbreviations: NA=not applicable, NR=not reported, RCT=Randomized controlled trial, NRCT=Nonrandomized controlled trial, MERSQI=Medical Education Research Quality Instrument.

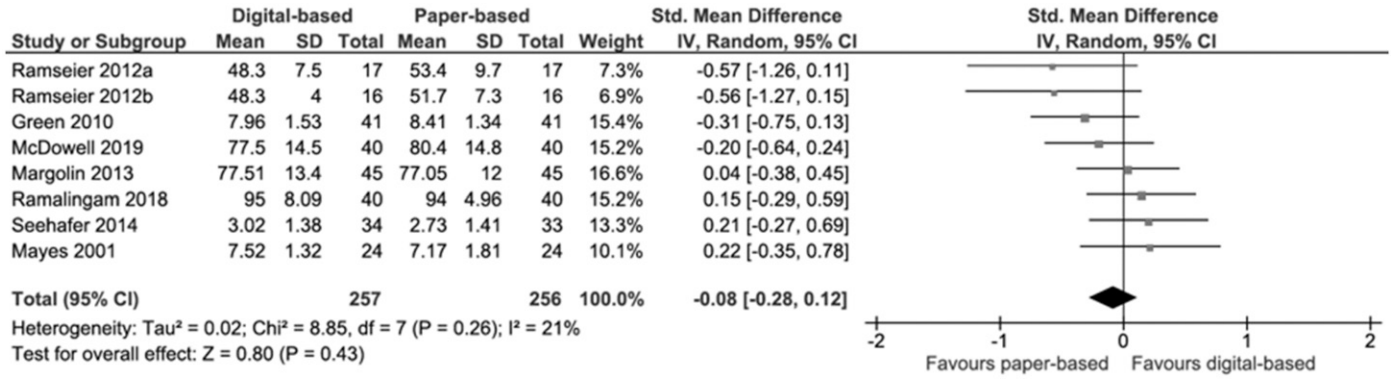

Figure 2. Forest Plot of Effect Sizes in Relation to Reading Comprehension

Two studies could not be pooled in the meta-analysis because of missing data.[30,34] The pooled effect size across eight studies revealed a negligible and nonsignificant advantage of paper- over digital-based reading media for reading comprehension (SMD = −0.08; 95% CI −0.28 to 0.12; $p = .43$; Figure 2). Heterogeneity was low ($I^2 = 21\%$).

In a cluster-randomized trial with medical students, Matthes, Herzig, Muller, Stosch[34] observed that a digital basic pharmacology e-book had a small, nonsignificant advantage over a similar paper book on final scores from a written multiple-choice examination (SMD = 0.27; $p = .08$). Similarly, in a study on introductory psychology students, Taylor[30] noted no differences in reading comprehension between students who used digital texts and those who used paper texts (the effect size and the p value were non-reported and could not be calculated based on the data presented).

We conducted three subgroup analyses: studies in which students read texts on topics related to HPE vs non-related to HPE; studies in which reading time was unlimited vs limited; and studies in which reading was supervised vs unsupervised. We observed a modest, significant difference ($p = .04$) in favor of paper-based reading for HPE-related texts (SMD = −0.36; 95% CI −0.69 to −0.03; $I^2 = 0\%$) compared to non-HPE related texts (SMD = −0.08; 95% CI −0.17 to 0.24; $I^2 = 0\%$). We found no significant difference ($p = .59$) between paper and digital reading regarding reading time. We observed a modest, significant difference ($p = .02$) in favor of paper-based reading in unsupervised settings (SMD = −0.57; 95% CI −1.06 to −0.08; $I^2 = 0\%$) compared to supervised settings (SMD = 0; 95% CI −0.19 to 0.18; $I^2 = 0\%$). However, the two studies meta-analyzed for unsupervised settings were drawn from the same paper. The quality of the evidence regarding the effect of reading media on reading comprehension was deemed low because of the high risks of bias across studies. However, inconsistency, indirectness, and imprecision were deemed not serious.

DISCUSSION

This is the first systematic review and meta-analysis to compare the effect of paper-based and digital-based reading HPE media on students' reading comprehension. We identified 10 studies published since 2001. The pooled effect size across eight studies revealed a negligible, nonsignificant advantage of paper-based over digital-based reading media for reading comprehension. Despite the small number of studies, a subgroup analysis revealed a modest significant increase in reading comprehension when students read paper copies of HPE texts compared to digital copies of the same texts. Risk of bias was generally high across studies, and the quality of evidence was low.

The negligible, nonsignificant advantage of paper-based reading found in this review is similar to the results of previous reviews.[9,10,14] These reviews found a small, significant advantage of paper-based reading over digital-based reading.[9,10,14] Our results also revealed marked variability regarding the characteristics of texts used to assess reading comprehension in HPE. Less than half of studies involved texts on topics related to students' discipline (eg, oral histology, optometry), whereas the rest used texts on non-related topics (eg, short fiction, microeconomics). Prior research has highlighted the importance of text characteristics, including topic and relevance,[1] when assessing reading comprehension. The significant difference in favor of paper-based reading for HPE-related texts echoes these previous findings; it suggests increased effects of reading media when considering texts relevant to students' discipline.

Our findings reveal that unsupervised, uncontrolled environments led to a small but significant difference in

favor of paper-based reading, when compared to supervised, controlled environments. This finding should be interpreted with caution: only two studies were unsupervised, both published by the same authors in a single article. That said, this finding may be explained by the fact that in unsupervised settings learners using digital devices may be more easily distracted by social media, digital notifications, or web browsing to name a few. This could explain why paper-based media appears to favor reading comprehension in unsupervised settings where learners are less exposed to such distractions. Research suggests that students regularly fall prey to distractions when using digital devices. Over a quarter of students self-report in-class, off-task distractions, and an estimated 50% of students' laptop time is spent on tasks unrelated to their studies.[40-42] Interestingly, the impact of digital-based reading is more negative for easy-to-read material than for hard-to read texts.[43]

Concerns for the distraction potential of digital devices such as smartphones or laptops may be minimized using e-readers, whose sole function is to enable reading. In our review, only one study focused on reading comprehension with e-readers[7], as compared to computer- and paper-based media and no difference was found. However, that study was conducted in a low distraction, supervised setting. Another study with fifth grade students compared reading on e-readers and paper and found no significant differences in students' attitudes, motivation or reading comprehension.[44] Additional studies must be conducted before the impact of e-readers on reading comprehension can be appropriately assessed. These studies should directly compare electronic devices with a potential for distractions (eg, laptops, computers, smartphones) to e-readers that limit such distractions. Besides the degree of distraction, future studies should be explicit about the tasks that students are asked to perform and the restraints that are in place when using the digital device.

More studies on the effect of reading media on reading comprehension in HPE are needed using rigorous study designs (eg, randomized trials, non-inferiority trials, factorial trials), interventions, and outcome measures. Indeed, given the high risk of bias of the published literature, future studies should be conducted as per the most recent standards for trials (eg, Consolidated Standards of Reporting Trials [CONSORT]).[45] Findings from properly designed RCTs, if consistent with our findings, may confirm that digital media is not inferior to paper-based media in terms of its impact on reading comprehension in HPE, a finding that could have significant implications for reading efficiency. Indeed, students reading computer passages read significantly faster than students who read on paper.[36] Discrepancies in reading speed may impact the time efficiency that is central to future health care professionals' practice.

Because of the various known advantages of digital media, namely, ease of access, organization, and eco-friendliness, the time-saving benefit of digital-based reading needs to be investigated. Educators and researchers need to consider that digital-based reading is only one educational component of modern e-learning programs, which may provide benefits for HPE that would not be possible through static, paper-based learning. For example, some e-learning programs include adaptivity features to personalize learning content through the consideration of each learner's knowledge. This can increase learning efficiency, reduce superfluous cognitive load, and support learner engagement.[46,47]

However, in a commentary by Fjortoft and colleagues,[48] the authors cautioned against pharmacy students' overreliance on technology and the possible impact it could have on their long-term memory, suggesting a concurrent association with a decreased passing rate for the national board examinations in recent years. Although many variables can explain such a decreasing trend, this review provides preliminary insight as to whether the reading media should be considered as part of curricular planning.

This systematic review and meta-analysis has various strengths and limitations. In terms of strengths, the protocol was prospectively registered and published, which enhances the transparency of the research process. Moreover, the search strategy was developed over several months with an experienced librarian to ensure specificity, sensibility, and replicability. Regarding limitations, outcome measures varied across studies. To address this variation, we conducted meta-analyses using SMD to standardize the results of studies to a uniform scale before pooling them. Furthermore, although we had initially planned to assess the effect of reading media on skill development and clinical behavior, the absence of such data in the studies included prevented us from doing so.

CONCLUSION

This review did not find any significant differences between digital and paper-based reading except when the topic of the text and its relevance to students' professional discipline was considered, in which case paper-based reading yielded a modest advantage over digital media. This review highlights the need for robust randomized trials in HPE using HPE-related texts to strengthen the quality and validity of the current evidence.

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