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Paper and digital reading: Differences and equivalences

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Abstract

Research objectives (aims) and problem(s): Reading is a skill that Homo sapiens has acquired over the last 10,000 years. Over the past 30 years, digital tools and media have profoundly transformed this exclusively human activity. This scoping review aims to understand how these new media have affected reading processes and whether they have transformed the cognitive and educational outcomes associated with reading.

Research methods: This article analyzes recent literature on reading, focusing on articles and research from the last 15 years. The methodology is based on a scoping review of peer-reviewed studies, meta-analyses, and empirical research examining paper versus digital reading. The point of view is neuroscientific and, based strictly on the most recent experimental data, attempts to offer new analytical tools for educational interventions.

Process of argumentation: For the sake of brevity, the topics of nighttime rest, implications of using smartphones in the evening, and the relationship with gaming have not been addressed. The article explores measurements of oral reading fluency to monitor learning progress; the effects of reading support on visual patterns, reading performance, and attitudes; self-regulated learning and metacognitive processes; and the relationship between digital/paper reading, memory, and attention.

Research findings and their impact on the development of educational sciences: The findings highlight essential aspects that must be taken into consideration in educational processes, particularly how digital versus paper reading modulates memory, attention, and

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neuroscience, emotions, school, social media, reading, attention, self-regulated learning, metacognitive processes

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metacognitive self-regulation. These results offer new analytical tools for designing evidence-based educational interventions that account for the cognitive transformations induced by digital media.

Conclusions and/or recommendations: The review concludes that digital media have significantly transformed reading processes, with measurable effects on cognitive and educational outcomes. It recommends that educational practices integrate awareness of these differences, promoting a balanced use of digital and paper-based reading in line with specific learning goals. Underexplored areas, such as the impact of digital reading on sleep and evening device use, warrant further investigation.

The problems of transferring massive amounts of information
between brains with different structures are not insurmountable. How-
ever, existing techniques for accomplishing this task
may still ultimately prove to be the most effective.
One of the most recent and advanced examples of these
techniques is in your hands right now.
(Hofstadter & Dennett, 1981)

Introduction

Reading is not only a process of decoding communication expressed in written form; it also presupposes the translation of visual (graphic) symbols into the verbal (articulatory) system. Precisely for this reason, one can justifiably assume that this process also includes in its organization elements of codification of communication. Therefore, basing ourselves on the constant possibility of using an integer information of communication (text), avoiding that the process takes place at the level of traces, which in the patient are particularly compromised (as evidenced by the repetition tests), we have the possibility of highlighting more precisely those phenomena of pathological inertia and inability to inhibit the emergence of secondary connections that we can observe in some experiments only in a limited way (Lurija, 1975).

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The primary purpose of this article is to investigate the neurocognitive and educational differences between reading on paper and reading on screen. Specifically, the review addresses the following research questions: How do paper-based and screen-based reading compare in terms of oral reading fluency, visual patterns, and reading performance? What role do self-regulated learning (SRL) and metacognitive processes play in mediating the effects of the reading medium? How do memory and attentional processes differ between paper and digital reading? What are the practical implications of these differences for educational interventions?

Numerous studies have shown how reading on paper and on a screen differ in terms of cognitive and behavioural aspects, such as eye movement (Köpper et al., 2016; Zambarbieri & Carniglia, 2012), reading comprehension (Singer & Alexander, 2017), and attitudes (Eijansantos et al., 2020). However, there are conflicting results on whether it is preferable to read on paper or a screen. Some studies reported increased reading time (Liu 2005) and lower comprehension scores (Mangen et al., 2013; Støle et al., 2020) when reading on a screen compared to reading on paper. Other studies reported that reading comprehension and reading time are similar (Hermena et al., 2017; Sage et al., 2019; Singer & Alexander, 2017). A consensus on these differences has not yet been reached.

One possible reason for this disagreement is that numerous factors influence the reading experience. Reading is a multifaceted process, influenced by word recognition, reading strategies, comprehension, and reader motivation (McLaughlin, 2012); therefore, different reading media have different advantages. Dillon (1992) argued that examining the differences of one or a few factors between reading on screen and reading in print is insufficient. Keller (2012) suggested five aspects of reading that should be taken into consideration when comparing reading in print and on screen. These include physical and attitudinal factors, such as eye fatigue and sensations, and performance factors, such as reading comprehension.

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Oral reading fluency

Teachers use oral reading fluency (ORF) measurements to monitor progress in learning to read and adapt instruction to students' individual needs. In ORF measurements, the child reads single syllables, words, or short passages aloud, and the teacher assesses in parallel where the child makes a mistake. Since administering ORF measurements on paper requires more effort on the part of teachers, computer-based administration is available. However, there are still doubts about the comparability of paper-based and computer-based testing methods (Jungjohann et al., 2023).

Few empirical studies have examined the differences in equivalence between computer-based and paper-based CBM for students (curriculum-based measurements are used for the early identification of students at high risk of severe learning difficulties). Predominantly, studies examine test formats in which students complete digital and analogue tasks independently and in groups. Many studies report significantly lower total scores on digital tests, concluding that the test formats are not comparable (Aspiranti et al., 2020; Bennett et al., 2008; Hensley et al., 2016; Seifert & Paleczek, 2022; Støle et al., 2020).

Schaffer Seits (2013) examined mode effects in ORFs based on whether reading texts were shown to students on paper or on the computer screen. Measured by total score, students read significantly more correct words in one minute on paper than on the screen. However, in both test modes, reading errors were documented manually by the administrator. This means that the assessment methods were identical for both computer-based and paper-based testing. Studies on the mode effect of summative reading assessments support Schaffer Seits' hypothesis that students read faster on paper and extend it to the conclusion that reading accuracy is lower on the computer (Lenhard et al., 2017).

Jungjohann and colleagues (2023) found that students showed significantly higher reading speed on the paper test, while no differences in reading accuracy were observed. The results confirm that there are no differences in item performance between the computerized and paper

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versions. Both values, the sum of the scores and the percentage of correct reading, can be used and compared in practice. However, before the total scores of the different test modes can be interpreted together, the difference in mean values must be taken into account.

In cross-sectional comparisons, both test modes can be used for research and teaching purposes, as they are reliable and valid. Teachers are already familiar with paper-based methods, and the comparability with other paper-based tests is greater. Computer-based tests offer automatic scoring and allow remote administration, reducing the teacher's workload. For school practice in particular, it is recommended to collect and evaluate data using only a single test form, as differences in the sum of scores of several test forms may vary for each individual child. Comparability in practice could be ensured by a parallel measurement with both test forms at the same time with subsequent compensation of the values. The results support the use of both test modes and, consequently, teachers should be trained in the use of both computer-based and paper-based tests.

The effects of reading support on visual patterns

As readers become increasingly familiar with reading on screen due to the proliferation of digital devices, the understanding of the impact of the medium on reading activity is also increasing. Jeong and Gweon (2021) examined the effects of reading medium (print or digital) on readers' visual patterns, reading performance and reading attitudes. The experimental results revealed that, in terms of visual patterns, readers showed shorter fixation durations and a higher number of fixations when reading in print than when reading on a screen. Reading performance, as measured by reading comprehension and reading time, was equivalent across all three media (paper, tablets, computers). However, in terms of reading attitudes, readers reported higher levels of perceived comprehension, perceived confidence, and perceived immersion and lower levels of perceived fatigue when reading a printed text than when reading from a device.

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While the performance gap between reading in print and on screen is narrowing, printed text may still be the preferred reading mode. The authors concluded that readers' performance was not negatively affected by the medium, probably due to their familiarity with digital devices. However, providing readers with a printed text might be the best solution in a learning environment, because readers have a more positive attitude towards print than towards digital devices (Jeong & Gweon, 2021).

The digital devices selected for use in Jeong and Gweon's study are commonly used for reading, and the insights gained explain how they differ from paper. Previous studies have focused on reading electronic resources from a computer and e-book environment. This study, on the other hand, focused on the comparison between printed paper and text on tablets or computers, which are increasingly used for reading, including for educational purposes (Jones & Brown, 2011; Siegenthaler et al., 2011). These data reinforce previous research on readers' visual patterns across different media. The results of the eye movement analysis indicate that screen reading is associated with higher cognitive load and skimming, which may prevent readers from reading in depth (Destefano & Lefevre, 2007; Hillesund, 2010).

Self-regulated learning and metacognitive processes

Self-regulated learning (SRL) and metacognitive processes are important in education because they contribute to effective learning and better school performance. Synthesizing the results of recent meta-analyses, Delgado et al. (2018) compared paper-based and digital reading for children and adults and highlighted the digital inferiority of the computer medium in fostering reading comprehension and learning tasks. Similarly, Clinton (2019) conducted a meta-analysis of 33 studies published between 2008 and 2018 that examined paper-based versus screen-based reading among children and adults. The results suggest that reading on paper is a more efficient way to comprehend material and improve test performance than reading on screen.

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Furenes et al. (2021) also conducted a meta-analysis of 39 studies on paper and digital reading in children aged 1–8 years. Their results confirmed previous findings that showed lower comprehension rates in digital reading than in paper-based reading. However, the authors stated that digital reading that contained visual cues and story vocabulary outperformed paper reading. Latini and Bråten (2022) conducted a study with a sample of 116 Norwegian university students on reading informational texts on tablets versus on paper. Taken together, these meta-analyses consistently indicate a disadvantage for digital reading in comprehension outcomes, although specific features (e.g., visual cues) can mitigate this gap.

Sergi et al. (2023) examined the presence and use of metacognitive processes among primary school students while completing computer- and paper-based reading tasks. The study showed that students were more likely to apply metacognitive SRL skills when reading on paper than when reading on the computer. Students showed greater planning in the paper-based condition than in the computer-based condition, but their behaviours and responses differed between school grades. Elementary students applied more types of planning and control processes in the paper-based condition and demonstrated monitoring and evaluation processes in both conditions. These results suggest that the use of prior information, the integration of multimedia and verbal cues, and the level of comfort with the reading medium influence students' SRL decision-making.

The learning process involves reaching conclusions through self-reflection and self-regulation strategies (Groß, 2021); these processes are also essential in reading comprehension (Earle et al., 2020; Qi, 2021). The most appropriate way for students to extract meaning while reading is through the conscious and controlled use of reading strategies, which requires a certain degree of metacognitive skills (Koutsouraki, 2020; Pressley & Afflerbach, 1995). In particular, reading comprehension is associated with increased SRL practices (Chen, 2009; Chen et al., 2019). Supports with 'scaffolding' have been positively associated with SRL processes and metacognitive strategies in computer-based educational environments

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(Serrano et al., 2018; Vidal-Abarca et al., 2010). Past research has shown that scaffolding strategies in online environments can enhance metacognitive skills in sixth-grade students, which depend on the use of prior knowledge in ninth-grade students (Bulu & Pedersen, 2012; Roussel, 2011).

Previous research has consistently shown that planning effects are present in older students (middle school, high school, and college students) during both computer-based and paper-based reading tasks (Follmer & Sperling, 2019; Manlove et al., 2007). Elementary students, on the other hand, were not found to use planning processes when using electronic media (Muis et al., 2015, 2016), which may be attributed to differences between task and medium. The results suggest that students apply planning to purposefully set learning goals and use strategies to achieve them. This is more evident in paper-based than computer-based reading tasks, as students may be more accustomed to organizing and completing paper-based tasks (Greene et al., 2010; Kuisma & Nokelainen, 2018).

The combination of current and past results indicates that planning, monitoring, control and evaluation develop during the primary school years, and this is slightly more evident in paper-based reading tasks than in computer-based ones. These findings broaden theoretical perspectives on SRL and metacognition: primary school students exposed to computer-based reading tasks show emerging self-regulatory and metacognitive traits as early as second grade, as well as increased strategy and flexibility in the upper grades. The multidimensional aspect of metacognition includes interconnected thinking processes and regulation skills, such as planning, monitoring and evaluation, which motivate students and improve academic performance (Brown et al., 1981; Flavell, 1979; Pintrich & de Groot, 1990).

Thus, it appears that primary school students have the potential to apply metacognitive regulatory strategies across reading media. Planning, monitoring, control, and evaluation are strategies to address reading deficiencies during computer-based and paper-based reading assignments across all school grades.

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Digital/paper reading, memory, and attention

The reading system is always the same, but its interactions with other cognitive functions (e.g., memory and attention) change, which means the result can differ (Dehaene, 2009). When reading on a screen, one is often confronted with a continuous bombardment of unrelated information, such as advertising banners. Whenever a change occurs in the visual scene, our brain has to pay attention to it. The attention system has been shaped by millennia of natural evolution to automatically capture sudden changes in the perceptual scenery: think of how many times our ancestors must have saved themselves from predator attacks thanks to their ability to immediately notice their appearance in the visual field.

Advertising exploits this automatic attention-directing mechanism, and so the banners that constantly appear and disappear on Internet pages are very effective in distracting us from the content we are reading. The human attention system is very powerful and flexible, allowing us to inhibit certain areas of our visual field. Accordingly, we can quickly refocus on our text after being distracted by the advertising message. However, these mechanisms require cognitive and neural effort, which inevitably detracts from in-depth text comprehension and reading speed (Crepaldi, 2020).

Even when the web pages we are reading are not overloaded with advertisements, they almost always contain so-called 'secondary content': a series of texts different from the main content of the page that are typically arranged graphically as a series of peripheral boxes. Think of online newspapers that use these peripheral boxes for news related to the main content. These boxes are typically less dynamic than banner ads, but in any case, they distract our attention from the primary reading content when our eye movements bring them into the visual field.

Any information overload, especially if secondary to the attentional focus at a given moment, results in a distraction of attention, perhaps very rapid and easily reversible, but still requiring cognitive and neural effort to manage. In this respect, reading on screen is certainly less effective than reading on paper (Crepaldi, 2020).

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Another advantage of reading on paper comes from 'spatial framing'. Our memories often rely on the spatio-temporal context in which we acquired them: our memory of a certain content is 'anchored', for instance, at the point in the book where we read it, or at the top right-hand corner of the page where it was contained. All these details of spatial context reinforce memory, placing the content in a 'support network' that helps us to acquire it, retain it for longer, and then retrieve it when we need it (e.g., when the professor asks a question).

The paper text probably lends itself better to framing effects, mainly because of its stability (electronic content changes) and the simplicity of the frame itself (the defined space of the pages and the book, which contrasts with the avalanche of information we are subjected to on the web).

Finally, there is the experiential and emotional component of reading. Here, multisensoriality, the integration of stimuli from the different senses, plays a fundamental role. One certainly reads with one's eyes, but not only with them: reading on paper brings with it a much richer experience, where touching the pages and holding a book in one's hands, or smelling its scent, complements and enriches our understanding of the text. This generates the feeling of having an experience closer to real life in the physical world, where the five senses work together at all times and integrate different information while referring to the same objects, the same sensations (Dehaene, 2009). It is perhaps these elements that generate the greatest sense of concentration when reading on paper.

Conclusions

This scoping review set out to answer four research questions concerning the neurocognitive and educational differences between paper and digital reading. The main findings are as follows. Regarding ORF and visual patterns, paper-based reading is associated with faster reading speed and distinct eye movement patterns (shorter fixations, more fixations), although reading comprehension performance is often equivalent. For SRL and metacognition, paper-based reading appears to facilitate

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greater use of planning, monitoring, and evaluation strategies, especially in elementary students. In terms of memory and attention, paper reading benefits from reduced attentional distractions, spatial framing effects, and multisensory integration, which support deeper encoding. The practical implications for education include the need to train teachers in both test modes, to consider paper for complex or lengthy texts requiring deep study, and to design digital reading environments that incorporate scaffolding and reduce extraneous cognitive load.

Electronic devices have led us to read much more often on screens than on sheets of paper. What changes from a cognitive point of view? Has the brain had to readapt and adjust its cognitive architecture? The real distinction is between readers and non-readers, rather than between paper readers and screen readers. In Italy, the ISTAT 2015 report indicates that about 75% of paper readers report having surfed the Internet in the last three months, compared to only half of non-readers (ISTAT, 2016). The proportion of people who have read online or downloaded books and e-books in the last three months increases as the number of paper books in the home increases, peaking among those with a well-stocked home library (> 200 books). This suggests that the most appropriate comparison between reading on paper and on screen is qualitative rather than quantitative: the preference between the two formats depends on what is read and for what purpose.

From the point of view of cognitive architecture, there is no reason to believe that reading changes much, whether on paper or on a screen. All processing stages are post-perceptual: they work on a type of information that abstracts from the particular perceptual event that generated it. For example, the neural activation that specifically determines the visual recognition of a word will be quite similar, whether it is read in capital letters or handwritten in cursive. The sub-lexical reading pathway (the one that serially translates individual graphemes into speech sounds) and the lexical reading pathway (the one that translates the entire word as a larger unit) will both be equally at work, regardless of the format of the reading medium. Visual word recognition systems interact dynamically with the cognitive system, and it is at this level that the

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neurocognitive differences between reading on paper and reading on a screen emerge.

However, these considerations should not be understood as a guarantee of better learning on paper: the fact that readers report greater efficiency and concentration when using that format does not necessarily mean they are learning better. Moreover, even cognitive phenomena (such as spatial framing and frequent switching of visual attention) do not necessarily lead to better learning. It is possible that readers – particularly younger readers, whose brains have had earlier exposure to screen reading – have developed a remarkable adaptation to digital reading, such that they are now able to learn information equally effectively on paper and screen, or perhaps even more effectively on screen.

As far as text comprehension in general is concerned, the majority of experiments do not seem to find a particularly pronounced effect of the medium: people learn equally well when reading on paper or on a screen. Neijens and Voorveld (2016) found that those who claim to be digital readers do not actually show any differences in text comprehension across reading media. Conversely, those who report being paper readers show slightly better learning scores in that format. Mangen et al. (2013) found that a group of teenagers seemed to understand written texts on paper better than on screen. Sparrow et al. (2011) showed that if new information read on a screen comes from an online search, the memory for the keywords is typically better than for the content found. In other words, the mechanism we typically use for online reading shifts our memory resources to the 'wrong place', helping us to remember the process that led us to obtain the information rather than the information itself. Ackerman and Goldsmith (2011) found that screen readers tend to overestimate their own performance, believing they have better learning than what can be objectively measured. In contrast, paper-based readers do not seem to show this phenomenon and are capable of more accurate self-assessments. The authors interpreted these results as a consequence of the perception of paper-based text as more conducive to in-depth study.

In summary, paper seems to be in a better position when it comes to reading complex, long texts that require close attention and for which

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one wants to keep a longer-lasting (or at least explicit) memory. The screen does not seem to perform worse in terms of memory or comprehension, but it is better suited to quick, more superficial reading, where what counts is implicit rather than explicit learning. Certainly, a difference in perceived effectiveness emerges, which does not therefore depend on objective performance but on the subjective experience of reading; in this respect, readers seem to prefer reading on paper for in-depth study. Future research should systematically investigate how digital scaffolding can compensate for the identified disadvantages of screen reading, particularly in educational contexts with younger readers.

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