DIGITAL VS HARD COPY: DIFFERENCES IN READING 1/3

A THREE-PART SERIES EXAMINING VISUAL NEEDS AT SCHOOL, READING, AND DIFFERENCES IN READING AND LEARNING BETWEEN DIGITAL VS. HARD COPY FROM AN OPTOMETRIST'S PERSPECTIVE.

Various national and private sector educational systems in most societies are converging towards a full digitization of teaching resources, producing an increasing shift in the educational paradigm. Regardless of the advantages that full digitization can provide within the educational field, we have to ask ourselves if the reading, visual, and cognitive performance is the same between formats: digital vs. printed. This has been a hot topic that has received much attention from various academic disciplines. In this series of three articles, we intend to address the issue from a multidisciplinary perspective—paying special attention to the implications that, from our point of view, are more relevant for the optometric practitioner. In this first article, we look at visual activities at school and the relationship between visual and academic abilities as we review the possible differences that may arise during reading in both formats.

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ACRONYMS USED

FVA Far visual acuity

P/NRA Positive/negative Relative Accommodation

VA Visual acuity

NVA Near visual acuity

AA Accommodative amplitude

ANSBDs Accommodative and Non-Strabismic Binocular Dysfunctions

DES Digital Eye Strain

URE Uncorrected refractive error

KEYWORDS

Digitization, reading, reading comprehension, school performance, visual skills, digital eye strain.

The digitization of education

The paradigm shift caused by the transition to learning via digital cannot be denied. On top of computers being present in every classroom and home, we can now use handheld mobile devices (tablets, e-readers, e-books and even mobile phones) to read any kind of material. This phenomenon also appears in the workplace and during our leisure activities. We have said it before—we live in a multi-screen world—a world where we are constantly jumping from one device to another to do anything and everything.

Even if most school systems in most developed societies are moving towards full digitization of their reading materials, and in spite of the benefits that full digitization offers this space (fig. 1), going digital comes with some concerns. Mainly, does it have a negative impact on the visual or cognitive processes? Is it better or worse to read on digital or paper? Does it have any negative repercussions to our visual health? Does it affect academic performance?

The caveat is the tremendous collection of clinical studies that examine every angle of this issue: how we read, what skills we need to read, how information is interpreted and decoded, what abilities we need to read correctly, what eye movements are associated with it, reading speed and comprehension, and reading and writing disorders, among other things. The perspectives and results of this research vary depending on the spelling of the language studied: phonetic vs. random (e.g. Spanish vs. English), or whether reading is silent or oral. We will not try to address all of these aspects in this article (which would be neither possible nor our main objective). It would also require us to generalize and simplify things, which would render some of our answers inaccurate or not fully accurate.

These considerations on reading and learning become far more important in the current context of confinement and post-confinement caused by the COVID-SARS 19 pandemic. According to UNESCO, nearly 160 countries closed their schools, representing nearly 90% of the world's academic population (5). Classes continue at home, using digital devices instead of classrooms. This situation was mirrored in the professional world as working from home (WFH) has skyrocketed. Both education and work are now digital. This trend was already growing before COVID-SARS 19, but there is every indication that the pandemic has accelerated it.

In any case, if digital devices hurt performance as several clinical studies and scientific papers suggest (1, 2, 3, 4), it could be linked to the greater demand they place on visual (mainly for accommodation or vergence), ocular, and cognitive resources. This effort may have some side effects on top of declining student performance. Why?

We know that poor use of backlit digital devices and computers is linked to a higher prevalence of visual, ocular and asthenopic symptoms, which have been grouped together and called Digital Eye Strain (DES). The WHO (6) officially recognised DES, noting that one of the key triggers is the time of use (7, 8). In the workplace, there are more DES-related problems than just the visual, asthenopic and ocular ones listed as its symptoms (9, 10, 11). It also turns out that it causes significant losses in work performance (12). We wondered whether longer use of digital devices (whether poor use or not) for reading tasks could cause an increase in the prevalence of DES or another syndrome in the school population, which could then lead to lower academic performance on top of increased health problems. We also wondered if it had any impact on the prevalence and progression rate of myopia, which is associated with this phenomenon (13, 21, 22), but that is a topic for a different article.

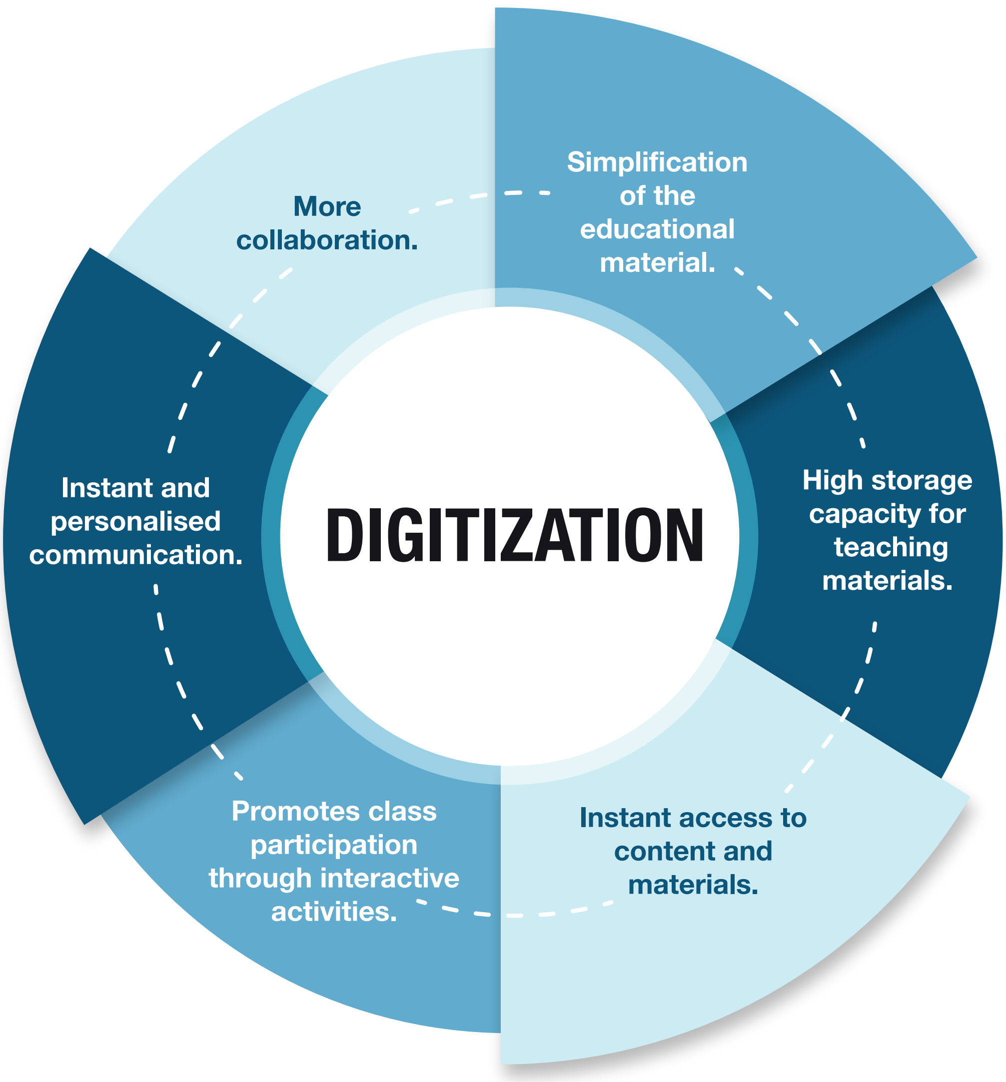
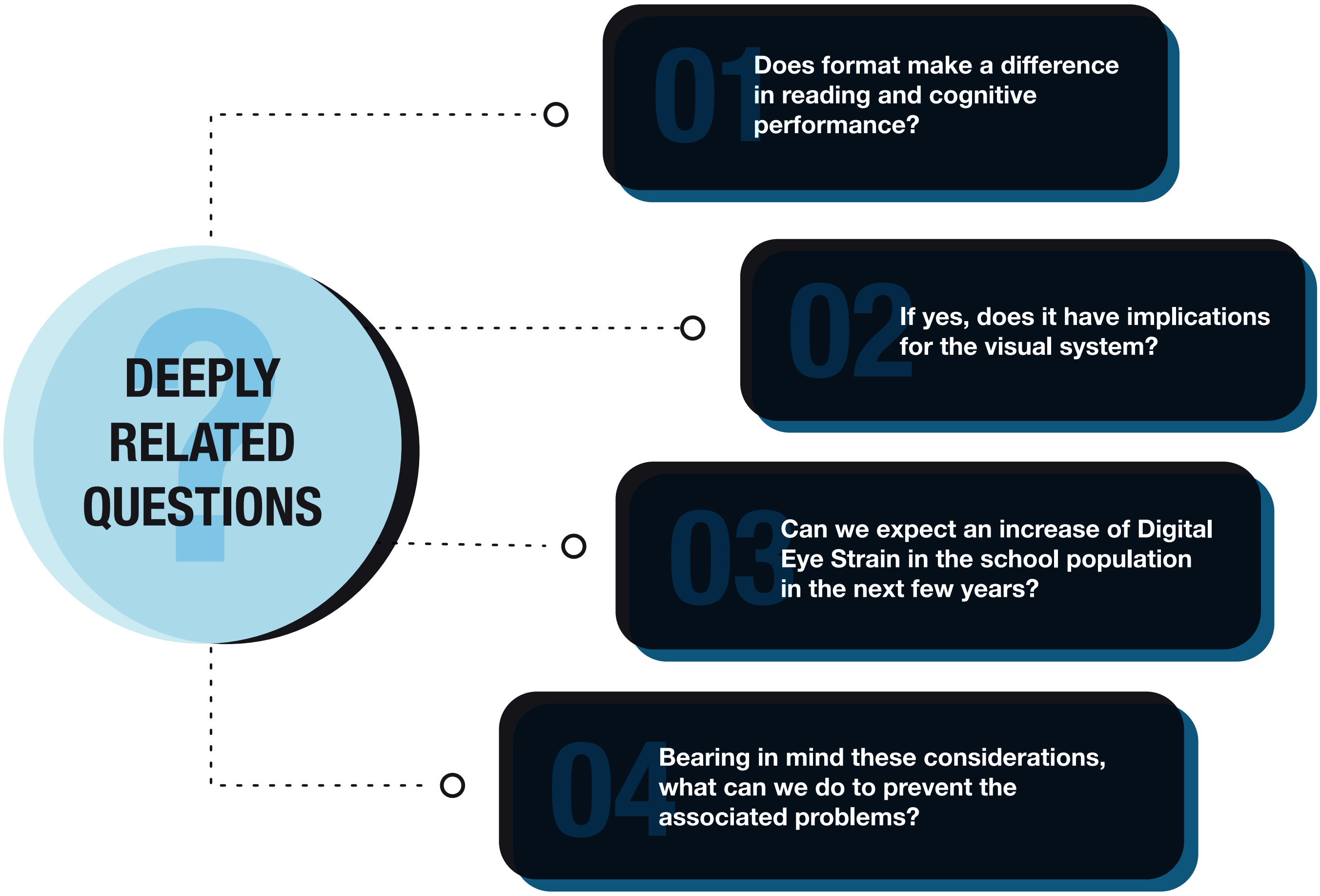


Fig.1. Some advantages of digitization in education. Digital devices are interactive and easy to use.
Plus, you can store and access more learning material in them. These are huge benefits of digitizing education.

Today, and now that we have reviewed the data and evidence provided by the clinical and interventional literature, we will address a series of deeply related questions:



To try to answer these questions, we will start from the beginning: school. What do children do there?

Visual requirements at school.

In the early 90s, Ritty et al (14) categorized the tasks that children do at school into four major groups:

- Distance tasks: when children work on something that requires them to look farther away, without switching to a closer visual object.
- Near tasks: when the child is reading or writing or performing a sustained activity with something nearby. The original study does not consider the use of screens in this group.
- Distance to near tasks: when children change their focus from one distance to another.
- General tasks: breaks, recreation, physical activity, etc.

On top of these "traditional" visual activities, Narayanasamy et al (15) rightfully adds:

- Activities with computers: tasks that require the use of a computer, whether desktop or laptop.

And to that, we add:

- Activities with digital devices: tasks that require the use of handheld digital devices. Technically we could lump this under near tasks, but due to the particular nature of its use and characteristics, we think they should be considered separately.

As you can see, visual activities in the classroom vary greatly. The demand for accommodation and vergence in a child's ocular system fluctuates greatly (16). But despite the apparent heterogeneity of these activities, clinical studies and research have shown that generally (despite the different focuses and educational models that exist) children perform near tasks most of the time. The hours vary, but it is usually close to half of the total school day (14, 16, 17, 18), at least for primary grades. While the visual effort required does depend on the activity, they mainly depend on the age of the child. Generally, the need for better visual acuity (VA) from near and far (NVA and FVA), increases as academic requirements increase (17).

Some studies have set the minimum NVA and FVA thresholds that would allow relatively normal performance in school, particularly in primary years. Primary years are, of course, when the critical learning processes are established. The thresholds are summarized below (15, 16, 17):

Study	Place and year	School grade	NVA (minimum)	FVA (minimum)
Negiloni et al.	India. 2017	Grade 4 to 12	0.31 LogMar	0.44 LogMar
Langford & Hug	USA. 2010	Grade 5	0.37 LogMar	0.73 LogMar
Narayanasamy et al	Australia. 2016	Grades 5 and 6	0.33 LogMar	0.72 LogMar

Table No. 1. Minimum visual acuity required for near and distance tasks in primary school, according to various studies.

These (relatively) low VA thresholders could explain why some children with uncorrected refractive error (URE) and lower VA can continue taking the classes with seeming normalcy and no negative effect on their reading performance. We see this relatively frequently in our consultations (often to our surprise), as well as how, considering the relationship between academic requirements and visual needs, some refractive errors pass by undetected (mainly, hypermetropia and astigmatism) until later years. Dirani et al's finding (18) that there is no link between VA and reading performance in early school years is surprising, at least if we consider the whole body of studies that connect visual skill with academic efficiency (19, 20). There are many things we should clarify from the above. For one, and as mentioned in Dirani et al's study (18), NVA and FVA are but a part of the whole set of visual capacities that can be used during visual activities. The VAs covered above are the threshold from which a child would have trouble following classes. However, VA is a relative measure, which does not give us a full picture of the efficacy of the visual system. Ritty et al (14) also make this point: "students with ocular motor dysfunctions may have difficulty meeting the behavioural expectations of the classroom". This has been confirmed by various studies, as well as in relation to motor skills in general (26, 27). Additionally, just because it is the minimum threshold, it does not mean that primary school students do not have tasks that require 20/20 VA (they do) (17), which some URE would make it very difficult to do. On top of all of this, a child's ability to achieve adequate academic performance and develop to his/her potential depends on a whole series of visual abilities, as well as other kinds of skills and influences from their surroundings.

These other factors have already been mentioned, but include oculomotor coordination, sensitivity to contrast, accommodation and vergence skills, and of course the presence of any ocular pathology. As such, and as Leone et al suggest, AV is not a particularly reliable measurement during paediatric screening (23), especially if the goal is to evaluate future performance or prevent learning or reading efficiency issues. In fact, several studies show clear links between health indicators (including certain visual skills), as predictors of future academic performance. For instance, Maples found that visual capacities better predicted academic performance than socioeconomic status (25). Some of the visual capacities he mentioned were visual motor efficiency and (though to a lesser degree) binocularity and accommodation (19). We believe this finding is particularly relevant.

This relationship between visual skills and academic performance is fundamental, and even more so in the development of the child's intellectual potential. A causal relationship between visual anomalies and lack of reading abilities in primary school has long been established. For example, Kavale K. in 1982 (28) found that children with URE were far more likely to have inferior reading skills than what they should have for their IQ (29). This makes us wonder, as did Thurston (30), how many children never develop adequate reading skills due to undetected or uncorrected vision problems? Bear in mind that among children with learning disabilities, a large part of them (though highly variable, between a range of 60%-80% (31, 32) whilst others claim 20% (38)) have accommodation and vergence deficiencies (31, 32). Their main issues are convergence deficit, accommodative insufficiency and accommodative and vergence inflexibility. Learning disabilities are defined as "a heterogeneous group of disorders manifested by significant difficulties in the acquisition and use of listening, speaking, writing, reasoning or mathematical skills."(33)

The relationship between visual and reading skills may be a little controversial, despite the large number of studies that show the link between both. There are also other studies that have not found this relationship or have not reached such obvious conclusions, like in Helveston et al (35) or Kiely et al (36). Some studies even suggested that in some cases, certain visual dysfunctions may be a consequence and not a cause of reading disorders (41). In any case, we can conclude that there is a positive relationship between visual skills, reading skills, and learning processes. We can say that students with cognitive impairment are at higher risk of having visual dysfunction, either refractive or another kind (pathological, binocular). These dysfunctions may have a negative influence in their learning process and daily activities (36).

These tasks, which are done during the learning process, can be divided into two basic phases (37): learning to read in the first years of school (phase 1), and reading to learn later (phase 2). In the 1st phase, adequate oculomotor control, visual memory and visual perception are the fundamental visual skills. In the 2nd phase, we need those and in addition need adequate accommodative-vergence balance, binocularity and stereo -visual acuity (36).

Ultimately, it seems that most of the learning and educational processes are reading-based, in both the action of reading and the interpretation of what was read. Vision is inherent to the entire process (even if there are equally effective tactile reading methods). This led to our next question: how do we read?

What is reading, and how do we read?

Reading is a complex skill that requires the coordinated performance of various visual, motor and cognitive processes. Regardless of the chosen medium, it is one of the most visually demanding tasks (42), understanding the text read is no less so. There are several reasons for this.

Unlike spoken language, which is coded into our genes and is inherent to the human species, reading (and thus, writing) is an invention. It is one of human's earliest tools. Saralegui et al. (39) said that the human brain is not intrinsically literary. Use of these tools required a "remodel" of various parts of the brain that were not built specifically for reading. A better term might be to "neurally recycle", like Dehane et al (40) suggest. This is what happens in the lateral occipitotemporal gyrus (fusiform gyrus).

But reading also involves ongoing cognitive processing, during which the brain continuously decodes multiple signals (44, 45). The brain interprets these signals, which can be visual or tactile, through a pre-established orthographical, lexical and phonological code that transforms them into units of information: words. The brain then decrypts and reveals the content of the text to be understood. The process is affected and influenced by many factors (43). The first factor is metalinguistics: the very structure of the language used. Sociological and environmental factors are external, and psychological and physiological ones are internal.

With all of these factors in play within the visual system, reading becomes a coordinated and complex harmony of

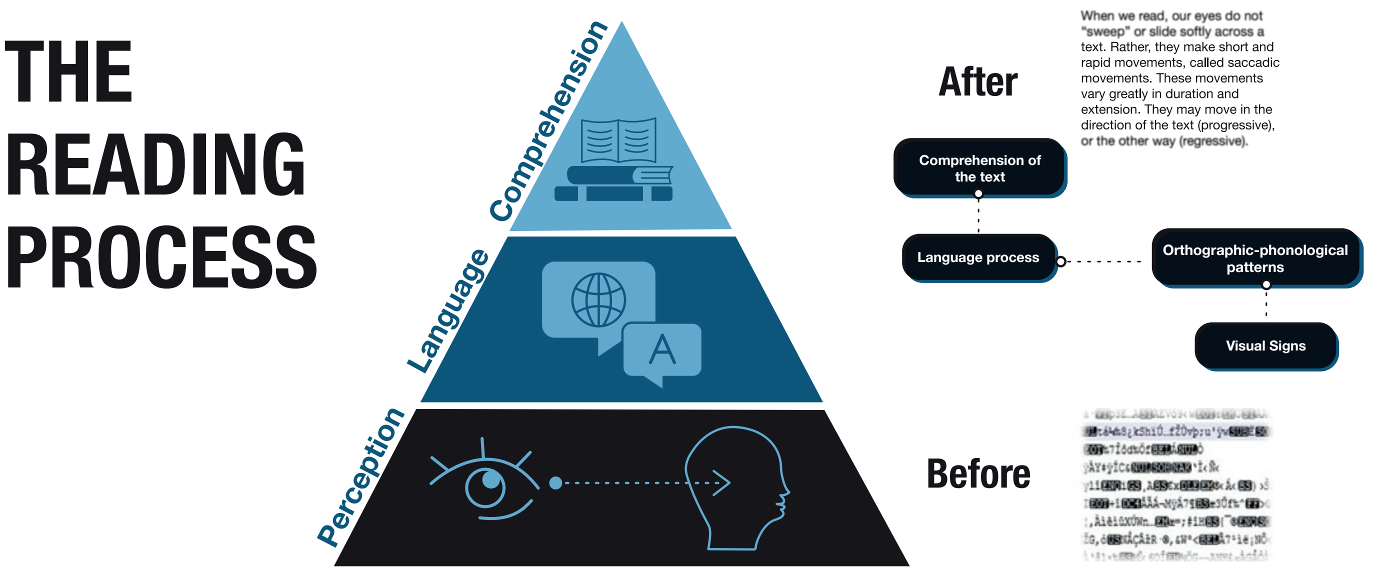


Fig. 2. The bottom of the reading process is the perception of the visual signals, which are then interpreted and processed through a shared code of orthographic and phonologic patterns: language, which is the vector for both transmitting and comprehending the message.

eye movements. The brain fires **fixations** and **saccadic** eye movements at a higher neuronal level (44), on top of controlling accommodation, myosis, and vergence.

When we read, our eyes do not "sweep" or slide softly across a text. Rather, they make short and rapid movements, called **saccadic** movements. These movements vary greatly in duration and extension. They may move in the direction of the text (progressive), or the other way (regressive). During saccades we barely extract any information (45, 46), which happens during **fixations**. Fixations are when the eye stays in one position for very short periods of time (200-250ms, but this duration also varies). Most of the studies and research use the quantity and percentage of regressive movements (the number of times we need to "go back" to read the text again), and fixation times as indicators of difficulty of processing a text. This metric is widely used (44, 56) and lets us objectively evaluate the visual-cognitive process behind reading.

The moment your eye extracts that information, there is a concept, one we find very important, called **perceptual span**. This can be defined as the region from which visual information can be encoded (44). Perceptual span is cognitive, not visual. Below are some of its identifying characteristics (44, 49, 50):

1. It is specific to the language used. It extends asymmetrically from right to left. The extent of its reach depends on the language. For example, in English it extends 14-15 characters to the right, and 3-4 to the left. The asymmetry would be reversed if it were in Hebrew or Arabic.
2. It can change within an individual, depending on the language used.
3. It is very similar among groups of readers who use similar alphabets and spelling, like Galician and Portuguese. The more "coded" the language is, like Hebrew, the smaller the "window' is. It becomes even smaller if the language is ideographic, like Japanese.
4. It varies with age and especially with the acquiring of reading skills.
5. Fundamentally, the perceptual span "window" is linear.

We are particularly interested in the last point [5], since perceptual span does not go beyond (neither upwards nor downwards) from the line being read in a given moment. We find this point highly relevant as a key to presenting the text in a hypertext and digital, especially if you consider point [4]. We will come back to this point later, in the second article in this series.

Numerous studies analysed these eye movements, perceptual span, and their relationship with cognitive processes, alertness, and attention as well as reading (e.g. 46, 47, 48, 51). Some of the findings were:

- Fast readers have fewer fixations of shorter duration. Their saccadic eye movements have greater extension, and they have very few regressive movements.
- Seasoned and fast readers have broader perceptual span.
- Highly trained (or qualified) readers have shorter fixation lengths. They extract information faster.

Regarding age:

- Children make more saccadic movements, especially regressive ones, with less amplitude. You could say they read in "hops".
- The younger the child, the longer the fixations last.
- Perceptual span is significantly lower in children, and it grows with age.

In terms of eye movement, children reach "adult" reading behaviour by 11 years of age (52). However, that does not mean that they have reached maturity at that moment. Rather, it means that the lexical and cognitive abilities and reading skill might determine the kind of eye movements made. Blythe & Joseph (52) mentioned: "these differences in eye movement behaviour may reflect slower or less efficient lexical identification in children compared to adults, despite the sentences [used in the investigation] being age-appropriate".

Therefore, reading skills (speed and comprehension of the text) would be strongly interrelated with visual abilities, which provide one another with mutual feedback. As Krieber at al (46) explained, "improved reading skills can reduce the number of eye movements needed to process written information."

Now we must determine if eye movements change when reading on digital devices, and if the reader's behaviour changes depending on the format. Zambarbieri & Carniglia's studies (54) say they do not: that reading an e-book is no different than reading a printed copy, at least in terms of oculomotor behaviour. Sigenthaler et al (55) confirmed that finding, when they compared reading on various devices (iPad and Sony Readers) to physical books. They found that fixation time does not change based on the format. The findings have not been the same for computers, which have much higher fixation times.

While a prior study by Siegenthaler et al (56) noted that "the reading behavior on e-readers is indeed very similar to the reading behavior on print", they did find certain differences in terms of the time spent on fixations. Namely, that they were longer on digital formats. This suggests that it requires more effort to extract information. However, there is a finding in this research that is especially relevant to us as optometrists: subjects could choose the font size that was most comfortable for them, which created different screen designs and sizes for the same text. So we could say that the larger the font size is (up to a threshold), the worse the reading skill is. This is typical behavior of emerging presbyopes and patients with uncorrected hyperopia who "resist" to compensate—for various reasons that are irrelevant—their refractive error for example, which in turn may affect their reading performance. To us, this is clear evidence in support of early prescription of URE on this age-group.

Nevertheless- looking at this through the lens of the clinical trials - if we assume that the fixation duration and percentage of regressive saccadic movements indicate a degree of difficulty while reading (24), then "reading using an e-book or a printed version does not differ significantly in terms of oculomotor behavior", according to Zambarbieri & Carriglia (53). However, if the many clinical trials (1, 2, 3, 4) that say that reading efficacy and cognitive performance are worse in digital vs. physical formats, are correct, but the oculomotor process related to reading is the same regardless of the format… then where does the problem come from? We find ourselves at an impasse.

We may have to analyse the existing disparities between these formats, and assess whether there are postural, visual, cognitive or other changes that could be caused by using all types of digital devices, and whether these changes can cause, in turn, differences in visual, reading, and cognitive performance. Now, we will focus on our behaviour when using digital devices and its characteristics.

End of part 1/3.

KEY TAKEAWAYS:

- Educational systems are moving towards full digitization, this leads us to a variety of questions, mainly a) are there any consequences linked to ocular health, and b) does the learning format have an impact on reading and cognitive performance?
- There is a positive relationship between visual skills, reading skills and learning processes. In fact, visual capabilities may predict academic performance.
- Reading in a digital format is no different than reading printed copy in terms of oculomotor behavior.
- There is some evidence that reading and cognitive performance is worse in the digital format, so we must analyse the existing disparities in terms of postural, cognitive and visual changes caused by different formats.

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