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Effect of overlay but not electronic blue filters on reading time and eye movements of children with developmental dyslexia

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This study aimed to examine the effects of colored blue electronic and overlay filters on reading time and eye movements of children with and without dyslexia. Children with ($n = 15$, 11.1 ± 1.6 years old) and without dyslexia ($n = 15$, 10.6 ± 1.7 years old) seated on a chair, with their heads stabilized by a forehead and chin support. They read different texts shown on a 14-inch laptop screen with no filter, blue electronic filter, and blue overlay filter. Eye movements were recorded using an eye-tracking system (ETG 2.0–SMI), and the total reading time duration, number and duration of fixation, and number and duration of saccades were obtained. Children with dyslexia showed longer reading durations and higher numbers of both fixations and saccades. In addition, they read faster with the blue overlay filter compared with the other conditions. Furthermore, the blue overlay filter reduced the fixation duration and increased the saccade duration. These results show that a blue overlay filter improves reading time in children with dyslexia owing to changes in eye movement patterns.

KEYWORDS

color tinted filter, eye movement, reading fluency, electronic filter, dyslexia

1 Introduction

Although reading seems to be a trivial task mastered by many individuals, it can be very complex and arduous for people who struggle to perform it. First, reading involves complex and coordinated eye movements that make successive saccades and fixations along a row of words; and second, it involves high cognitive functioning to obtain the context of the message. Unfortunately, ∼10%−20% of the population experiences difficulties in reading and are diagnosed with dyslexia (Katzir, 2009), or suffer from visual stress, especially individuals with dyslexia (Singleton and Henderson, 2007; Singleton and Trotter, 2005).

Visual stress occurs because of a specific condition involving an unnatural spatial structure and an excess of contrast energy, at spatial frequencies, available to the visual system (Wilkins and Evans, 2022). Such condition can compromise, for instance, reading. The use of colored filters has been suggested to minimize and even avoid such distress (Wilkins and Evans, 2009) and is employed to benefit reading performance of children with dyslexia (Denton and Meindl, 2016; Henderson et al., 2013; Razuk et al., 2018). Some of the symptoms of visual stress include feelings of eyestrain and excessive brightness leading to several distortions such as fading, blurring, flickering among others (Wilkins, 2002). In this case, the colored filters would reduce some of the visual distortions that some people, including some with dyslexia, experience during reading (Wilkins and Evans, 2022), leading to reading improvements. Despite these evidences, the use of colored-filtered spectacles to reduce the impact of visual stress on reading is still much controversial, especially in individual with dyslexia because not all of them show such distress, and many investigators in the scientific community remain highly skeptical about their benefits.

The impact of colored overlays on reducing reading difficulties in children with dyslexia has been observed in a few studies (Guimarães et al., 2020; Henderson et al., 2013; Ray et al., 2005), but not in others (Denton and Meindl, 2016; Ritchie et al., 2011). Recently, Razuk et al. (2018) showed that colored green overlays improved reading capability in children with dyslexia and this improvement was associated to shorter eye fixation duration, indicating that reading improvement was directly related to the eye movement pattern as children with dyslexia scanned rows of words.

The effects of colored filters on the central nervous system have also been investigated. For instance, Kim et al. (2015) observed that the reading speed of patients with Meares-Irlen syndrome improved by more than 20% with colored filters, and that 80% of the patients chose a blue filter. Moreover, significant activations in the left-middle and superior temporal cortices were observed during reading with filters but not during reading without filters (Kim et al., 2015), regions known to be involved in comprehension, and more specifically, semantic and syntactic integration (Friederici et al., 2003; Vandenberghe et al., 2002). Thus, the effectiveness of colored filters in improving reading performance, at least in patients with Meares-Irlen syndrome, might be related to several changes in eye behavior patterns (Razuk et al., 2018) and central nervous system activation (Kim et al., 2015).

Colored filters have been initially suggested as overlays, plastic transparent-colored sheets, that placed on papers or on screens, tinted text printed or presented on a computer screen, respectively. Also, colored filters can be adjusted to spectacles in which special glasses are equipped with color-tinted lenses that can be worn as regular glasses. Despite all these possibilities, there has been a significant increase in the use of electronic devices (smartphones, tablets, computers, etc.) nowadays in which texts are shown for reading and, consequently, users can choose many electronic features and background colors (Wilkins, 2002). Such electronic features allow users to change hue and intensity (saturation) separately and provide readers with manipulations that mimic colored overlay filters.

Despite the increasing number of studies and possibilities of changing colors for reading and of changing the reading environment, to the best of our knowledge, no study has examined the possible effects of background coloring on electronic features for text reading. There is no information regarding the possible effects of such electronic devices on eye movement patterns during reading, which is imperative not only in electronic device reading, but also in general reading conditions (Guimarães et al., 2020). Therefore, this study aimed to examine the effects of colored blue electronic and overlay filters on reading time and eye movements during reading in children with and without dyslexia. We hypothesized that both blue electronic and overlay filters would improve reading time in children with dyslexia.

2 Materials and methods

2.1 Participants

Fifteen (11.1 ± 1.6 years old; six males and nine females) children with dyslexia and 15 age-matched children without dyslexia (10.6 ± 1.7 years old; three males and 12 females) with no reading difficulties participated in this study. Children with dyslexia were recruited from local phonological clinicians after undergoing a complete evaluation and dyslexia screening assessment, including neurological, psychological, and phonological capabilities, according to the Brazilian Dyslexia Association. None of them had any other known comorbidity and when indicated children wore corrective glasses. Children without dyslexia were recruited from the local community, with no indication of reading difficulties or any other known difficulties. All children's participation in the study was conditional upon permission provided by their parents, who signed an informed consent form. The local institutional review board approved both the study procedures and the informed consent forms.

2.2 Procedures

Each child and their respective legal guardian were invited to visit the laboratory where the experimental session was conducted. First, they were asked to wear an eye movement tracking system [Eye Tracking Glasses (ETG 2.0 SMI)] to capture eye displacement (iViewETG SMI, version 2.7.1) and to sit comfortably on a chair with the head stabilized by a forehead and chin support. Calibration procedures were performed as per device requirements, wherein the child had to fixate on a three-point matrix distributed on the reading area in which the texts would be presented on the monitor.

The reading tasks followed similar procedures adopted in a previous study (Bucci et al., 2012), with different three-line texts taken from a children's book and presented on a portable computer monitor (LG 14" screen) placed in front of each child at a distance of approximately 30 cm. The paragraph contained ∼35 words and 150 characters, displayed using black "Courier" font, size 18. Texts were matched for structure and difficulty (35–37 words, 162–167 characters, 65–71 Flesch Index), extracted from children's book, and children were not familiar with them. The child was asked to read the text silently, and at the end of each text, experimenters asked the child three specific questions to ensure that they read and understood the text content. All children showed understanding of the content of the reading.

The reading was performed under three filter conditions: (1) no filter, (2) blue overlay filter, and (3) blue electronic filter. In the no-filter condition, the monitor background was white. For the blue overlay filter, the computer monitor was covered with a blue overlay Irlen® filter. For the blue electronic filter, the monitor color screen was changed using the ColorVeil® free package, manipulating the color matrix, saturation, luminosity (140, 240, and 167, respectively), and color tonalities (red, green, and blue; 100, 177, and 179, respectively). Given the visible colors from the shortest (violet) to the longest wavelength, and that there is a tendency for people to prefer colors with short wavelengths (Guimarães et al., 2020; Razuk et al., 2018), blue was selected

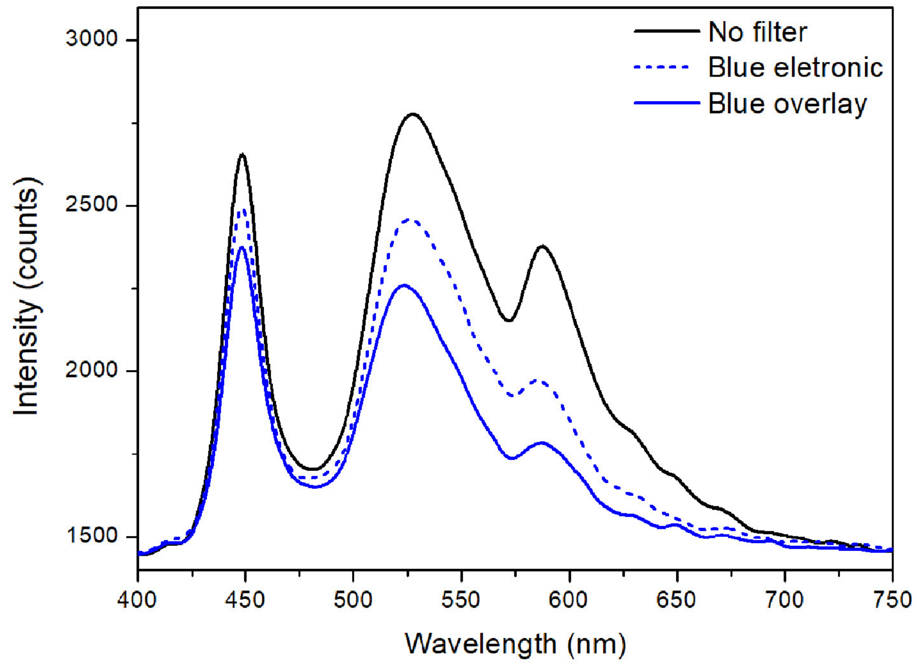

FIGURE 1
Intensity along wavelength spectrum of the colors displayed during reading by children with no filter, blue electronic filter, and blue overlay filter.

for being close to the shortest wavelength color (violet) in the color spectrum. The color spectrum composition of each condition was examined using a spectrometer (Ocean Optics USB 2,000). The luminosity sensor was fixed near the participant's eyes in front of the monitor. SpectraSuite® software was used to acquire and display the wavelength spectrum for each color condition (Figure 1).

Eye movements were recorded (120 Hz) throughout the reading period for each child and were stored for further analysis. Prior to the reading task, the children were instructed to read as quickly as possible and fixate on a dot displayed on the screen until the text was presented. After reading the text, the children were instructed to fixate on the dot displayed at the bottom of the monitor. One trial per filter condition was acquired for each child, and the order of each filter was randomized among the children.

2.3 Data analysis

The horizontal and vertical eye coordinates were exported and analyzed using a dedicated routine written in MATLAB. Specifically, the beginning and end of the reading task were identified and validated by visual inspection of the eye movement video from the eye-tracking system, and the total reading time (in seconds) was obtained. The specific segment of data related to reading was delimited, and the software (BeGaze, SMI, version 3.7) automatically detected both the onset and end of each saccade with a built-in saccade detection algorithm (employing a parameter of a minimum duration of 22 ms, peak velocity of 40°/s, minimal fixation of 50 ms, and the start and end as 20 and 80% of the saccade length, respectively). The onset and end of each saccade identified by the algorithm were visually inspected and confirmed by an investigator. The following variables were obtained based on each saccade detection: number of fixations (events in which the eyes were focused on a specific text area), mean fixation duration, number of saccades (events in which the eyes moved from one fixation point to another), and mean saccade duration. These variables were obtained for each experimental condition.

2.4 Statistical analysis

After testing for normality and homogeneity of variance assumptions, an analysis of variance (ANOVA) and two multivariate analyses (MANOVA) with the group (dyslexic and non-dyslexic) and filter conditions (no filter, blue electronic, and blue overlay filter) as factors, with the last one treated as a repeated measure, were performed. Dependent variables included the total reading time for ANOVA, number and mean fixation duration for the first MANOVA, and number and mean duration of saccades for the second MANOVA. When necessary, univariate analyses and Tukey HSD *post-hoc* comparisons were performed. All analyses were performed using SPSS software, and the alpha level was set to 0.05.

3 Results

Figure 2 shows the total reading time for both groups under all three experimental conditions. ANOVA showed group ($F_{1,28} = 19.02$, $p < 0.001$) and condition effects ($F_{2,27} = 4.20$, $p < 0.05$), and the interaction between group and condition ($F_{2,27} = 3.49$, p

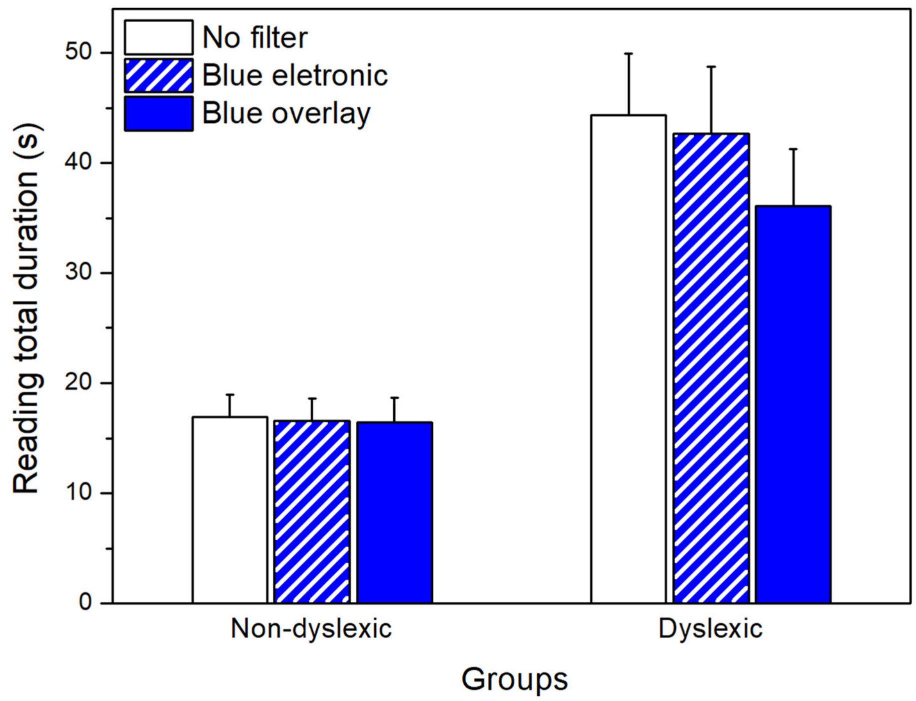

FIGURE 2
Mean (± SE) of total reading time for children with and without dyslexia with no filter, blue electronic filter, and blue overlay filter.

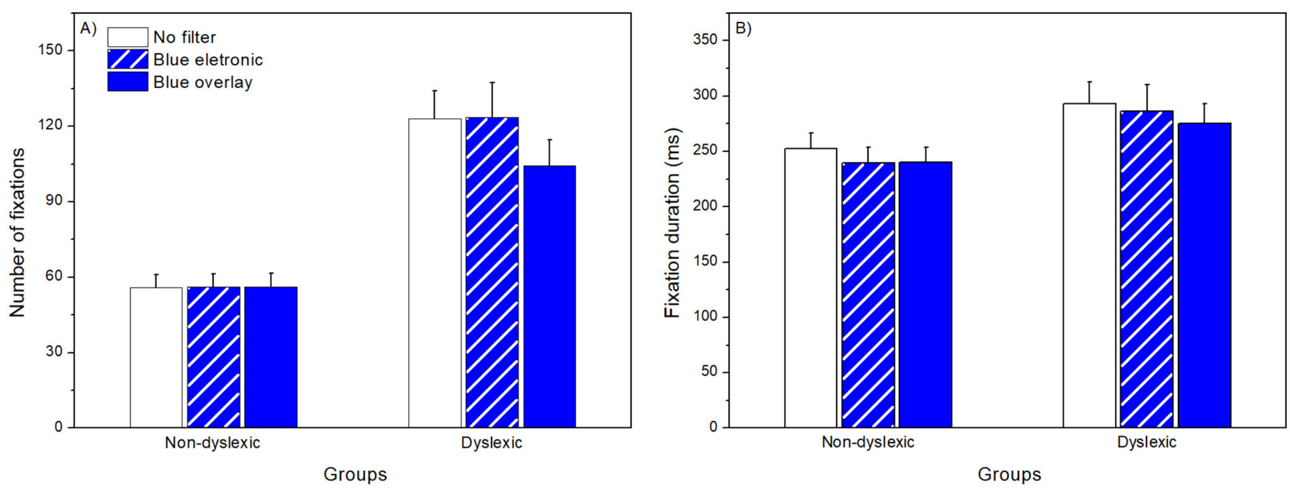

FIGURE 3
Mean (± SE) of fixation number **(A)** and fixation duration **(B)** for children with and without dyslexia with no filter, blue electronic filter, and blue overlay filter.

< 0.05). Children with dyslexia spent more time (41.05) reading than the children without dyslexia (16.65). *Post hoc* tests showed that children with dyslexia read faster in the blue overlay (36.12) condition than in the blue electronic (42.70) and no filter (44.34) conditions ($p < 0.05$).

Figure 3 shows the number of fixations and the mean fixation duration for both groups and all experimental conditions. MANOVA showed group (Wilks' Lambda = 0.492; $F_{2,27} = 13.95$, $p < 0.001$) and condition effects (Wilks' Lambda = 0.588; $F_{4,25} = 3.32$, $p < 0.05$), but no interaction between group and condition (Wilks' Lambda=0.845; $F_{4,25} = 1.15$, $p > 0.05$). Univariate analyses indicated that the number of fixations was higher in children with dyslexia (116.95) than in children without dyslexia (56.06) ($F_{1,28} = 28.85$, $p < 0.001$) and that there was no group effect for the mean fixation duration ($F_{1,28} = 2.96$, $p > 0.05$). The analyses also showed that the mean fixation duration was marginally different across the filter conditions ($F_{2,56} = 2.69$, $p = 0.057$), and *post hoc* analyses indicated shorter fixations with

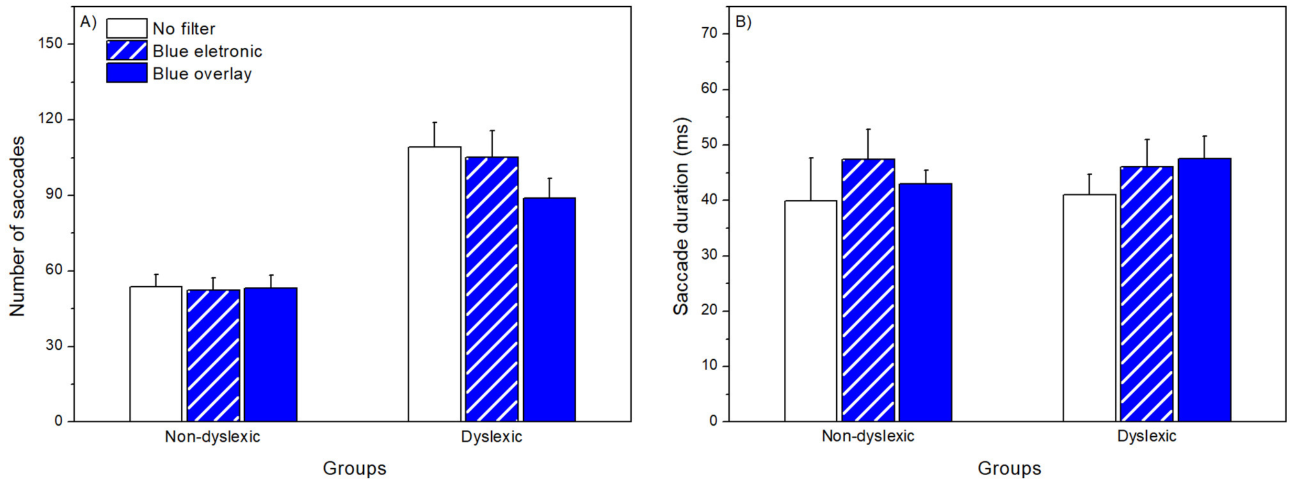

FIGURE 4
Mean (± SE) of saccadic number **(A)** and saccadic duration **(B)** for children with and without dyslexia with no filter, blue electronic filter, and blue overlay filter.

both blue electronic (262.74) and overlay (257.68) filters than with no filters (283.07) ($p < 0.05$). In contrast, the number of fixations did not differ across the filter conditions ($F_{2,56} = 2.02$, $p > 0.05$).

Figure 4 shows the number of saccades and the mean saccade duration for both groups in all three experimental conditions. The MANOVA showed group (Wilks' Lambda = 0.048; $F_{2,27} = 13.92$, $p < 0.001$) and condition effects (Wilks' Lambda = 0.588; $F_{4,25} = 4.38$, $p < 0.01$), but no interaction between group and condition (Wilks' Lambda=0.829; $F_{4,25} = 1.29$, $p > 0.05$). Univariate analyses indicated that the number of saccades was higher in children with dyslexia (101.13) than in children without dyslexia (53.22) ($F_{1,28} = 28.78$, $p < 0.001$), and that there was no group effect for the mean saccade duration ($F_{1,28} = 0.08$, $p > 0.05$). Univariate analyses also showed that the mean saccade duration was different across the filter conditions ($F_{2,56} = 3.34$, $p < 0.05$), and *post hoc* tests indicated a longer saccade duration for both blue electronic (46.75) and overlay filters (45.28) than with no filters (40.48) ($p < 0.05$). In contrast, the number of saccades did not differ across the filter conditions ($F_{2,56} = 2.37$, $p > 0.05$).

4 Discussion

This study aimed to examine the effects of colored blue electronic and overlay filters on reading time and eye movements of children with and without dyslexia during reading. The results showed that children with dyslexia read slower than those without it, but the reading speed of children with dyslexia improved with the blue overlay filter compared to the blue electronic and no filter conditions. Blue filters (electronic and overlay) also reduced and increased the fixation and saccade durations, respectively. The findings partially supported our hypothesis and are discussed below.

Children with dyslexia took much longer to read the texts than children without dyslexia, which aligned with recent studies (Guimarães et al., 2020; Razuk et al., 2018). Although reading speed varies among children with dyslexia, our results showed that they spent more than twice as much time as children without dyslexia. Moreover, this much longer time to complete the reading, accompanied with different eye behavior indicating difficulties to recognize letters and words in order to understand the content of the text. Such a difference in total reading time clearly depicts the struggle experienced by these children, which can impact several daily activities.

An important finding observed in this study was that the overlay blue filter improved reading time of children with dyslexia, showing a significant reduction in reading time, partially supporting our hypothesis. These results resemble those from recent studies which showed that a green filter promoted reduction in the total reading time of children with dyslexia (Razuk et al., 2018); other studies have also shown the beneficial effects of overlay filters on reading difficulties (Guimarães et al., 2020; Henderson et al., 2013; Ray et al., 2005). Thus, although the use of spectral filters remains controversial, our results shed light on the importance and contribution of overlay filter use in improving reading performance in children with dyslexia. Colored filters change the visual stimuli that are available for the central nervous system processing, reducing the cortical hyper-excitability and leading to consequent reduction of visual stimulus contrast (Wilkins, 2002). Moreover, Kim et al. (2015), using functional magnetic resonance imaging (fMRI), showed significant activation of regions involved in comprehension and semantic and syntactic integration during reading with colored filters. Finally, most of the patients with visual stress selected blue filters and they improved about 20% of their reading speed (Kim et al., 2015). Both results are in line with results observed in this study.

Our findings also showed that improvement in reading time was accomplished by reducing the fixation duration. During reading, the fixation period is important for identification, memorization, and comprehension of words, and it is well known that children with dyslexia exhibit oculomotor impairment (Bucci et al., 2012; Seassau et al., 2014). Reduction in fixation duration was also observed with the use of a green overlay filter (Razuk et al., 2018), and along with our results, the use of spectral filters leads to important and beneficial effects on eye movement patterns related to improvement in reading time.

However, it is important to note that reduction of fixation duration in this study was observed in both dyslexic and non-dyslexic groups and with both overlay and electronic filter conditions. Despite the differences in fixation duration, no difference in reading time was observed in the non-dyslexic group. Thus, it seems that the blue filter might have also promoted accommodation of eye movements, with shorter fixation duration not sufficient to impact the task performance (in this case, the total reading time). Such results were expected because colored tints can also promote functional implications for people without reading difficulties, such as dyslexia (Wilkins and Evans, 2022). Moreover, the reading time of children without dyslexia was already much shorter, and differences in eye movement patterns may have been insufficient for reducing this time.

Children with dyslexia showed a higher number of fixations and saccades (Figures 3A, 4A, respectively), indicating more complex eye movements during reading. Razuk et al. (2018) also observed an increased number of pro- and retro-saccades, suggesting that children with dyslexia return to letters and words previously seen, as the content may not be acknowledged by the central nervous system. The results of the present study are in line with these observations, although we did not discriminate between pro- and retro-saccades. However, a higher number of saccades is indicative of children with dyslexia moving their eyes forward and backward more often than children without dyslexia.

Finally, a striking result of this study was the difference in the total reading time observed between the overlay and electronic filter conditions. The reduction in reading time was only significant in the blue overlay filter condition. The use of a colored filter seems to promote alleviation of cortical hyperexcitability, as suggested by Wilkins (2002), leading to a decrease in the contrast of the visual stimulus and consequently allowing better reading performance. Our results showed that such alleviation occurred only in the overlay filter condition. This suggestion is in line with an fMRI study by Kim et al. (2015), who showed that in patients with Irlen syndrome, the regions in the left-middle and superior temporal cortices involved in comprehension were significantly activated during reading with a colored blue filter (80% of the participants selected blue filters) compared to reading without a colored filter.

Interestingly, the effect on reading time was only observed when children with dyslexia read with the blue overlay, but not with the blue electronic filter. Such differences owing to the different filters can be explained by the observed spectrum displayed in Figure 1. As shown, because the monitor displays colors based on the RGB color model, it is possible to identify the three peak components (Red-580; Green-530; and Blue-450 nm). In the no-filter condition, the intensity in these three components was the highest compared to both filter conditions. Moreover, both the blue overlay and electronic filters significantly reduced the color components at all wavelengths but were more accentuated in the wavelengths of the green and red components. This reduction was expected because the filter was blue, meaning that the blue light remained, but the other light wavelengths attenuated, and the spectra showed such a filtering effect. However, the blue overlay filtering attenuation was more accentuated than that observed for the blue electronic filter. Thus, considering that the colored filter possibly alleviates abnormal excitability of cortical areas (Wilkins, 2002), the stimulus provided by the blue overlay was less excitable than the electronic filter and, consequently, did not significantly impact reading time.

Finally, there is a need to further understand not only the impact of colored filters on reading capabilities, but also the possible effects on eye movements. It is well known that children with dyslexia show different oculomotor patterns than children without dyslexia (Bucci et al., 2012; Seassau et al., 2014), but the effects of colored filters still need to be understood. Moreover, considering the changes in wavelengths due to filter and color manipulations, this is an important matter considering the impact on readers with dyslexia. These findings are promising; however, several issues need to be considered for more defined color changes in the reading capabilities of children with dyslexia.

5 Conclusion

Blue overlay filter improves reading time and oculomotor patterns in children with dyslexia. In contrast, the blue electronic filter did not improve reading time, although it did promote changes in eye movement patterns. The difference in filter impact on reading is aligned with the observed attenuation of the color light wavelength, in which the overlay attenuation of green and red colors was larger than that observed when applying the electronic filter.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Plataforma Brasil CAAE: 19418419.7.0000.5465. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

JB: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing. RM: Data curation, Formal analysis, Methodology, Writing – review & editing. IG: Data curation, Formal analysis, Methodology, Writing – review & editing. AB: Data curation, Formal analysis, Methodology, Writing – review & editing. MH: Conceptualization, Methodology, Writing – review & editing. GF: Data curation, Formal analysis, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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