Analysis of Maxwell's centroids in scholars aged 7 to 14 years with and without dyslexia

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Abstract

The aim of this study was to investigate the general characteristics and magnitude of the Maxwell's centroids in students aged 7 to 14 years, with and without dyslexia. Fifteen students diagnosed with dyslexia and 11 typically developing peers participated in the study. Each participant sat facing a device positioned on a table and viewed a white screen through a central aperture of a viewing tube. The tube contained blue and green optical filters that were manually alternated by the experimenter using a lever. As the filters changed, participants identified a dark spot on the screen and subsequently reproduced the perceived image on a tablet, from which data were stored for analysis. Ocular dominance was assessed using the fenestrated card test. A custom LabView program (National Instruments, Inc.) was used to record the contour of the reproduced images and calculate the corresponding radius, area, circumference, and x-y coordinates were calculated. Using these coordinates, an asymmetry coefficient between dominant and non-dominant eyes was computed with a custom MATLAB routine (MathWorks, Inc.). Overall, the characteristics of Maxwell's centroids were similar between groups, although the magnitude of centroids parameters was consistently greater among students with dyslexia.

Introduction

Dyslexia is widely characterized as a marked difficulty in reading, decoding, and spelling words, regardless of an individual's educational background, cognitive ability, or motivation (Adlof & Hogan, 2018; Ferrer *et al.*, 2010; Peterson & Pennington, 2015). Importantly, the reading challenges experienced by individuals with dyslexia are not attributed to learning disabilities (Tunmer & Greaney, 2010), but rather to slow and effortful reading (Shaywitz *et al.*, 2021). As a result, even when enrolled in mainstream educational settings, individuals with dyslexia typically struggle to develop fluent and accurate reading, writing, and spelling skills (Fletcher, 2009).

Because vision plays a central role in the act of reading, the visual system has been examined as a potential contributor to the manifestations of dyslexia (Barela *et al.*, 2025; Bucci *et al.*, 2012; Razuk *et al.*, 2018; Seassau *et al.*, 2014). Among the many components of this complex system, particular attention has been directed to a region of blue cones known as the area of Maxwell's centroids (Le Floch & Ropars, 2017).

Maxwell's centroids are perceived as a dark circular spot comprised of three concentric zones: a central point, a lighter intermediate ring, and an outer halo (Miles, 1953). Their shape, however, is not uniform across individuals and may vary according to the relative distribution of red and blue cones in the fovea. For example, some centroids display larger or smaller intermediate rings, others are characterized only by the halo, and some lack the central point altogether (Isobe, 1955). Such morphological variations are linked to differences in the structure of the foveal wall and the foveola.

Le Floch and Ropars (2017) explored these centroids in adults with and without dyslexia. In adults without dyslexia, the authors observed clear asymmetries between the right and left eyes. Typically, the dominant eye exhibited a more circular centroid, whereas the non-dominant eye showed a more irregular and elliptical shape. This pattern was interpreted as an expression of neural selection processes, through which the central nervous system preferentially relies on input from the dominant eye. In striking contrast, adults with dyslexia demonstrated symmetrical centroids, with highly similar configurations in both eyes (Le Floch & Ropars, 2017). According to the authors, symmetrical centroids provides to the central nervous system nearly equivalent visual signals from both eyes, which may hinder the extraction of fine visual details. They proposed that this absence of asymmetry could interfere with the establishment of a dominant eye, thereby complicating the processing of visual information in individuals with dyslexia.

Given these findings in adults, an important question emerges: does the same symmetry in centroids occur in children and adolescents? Investigating this possibility may deepen our understanding of how neural connections develop within the central nervous system and how these developmental processes relate to dyslexia. Furthermore, if such symmetry is present early in life, it may hold promise as a potential indicator for the early detection of dyslexia, well before children reach the age at which reading skills are typically acquired. This idea is consistent with evidence that visual acuity develops progressively after birth, reaching a functional peak around four years of age as foveolar cones mature (Green, 1970; Yuodelis & Hendrickson, 1986).

Based upon this background, the present study aimed to investigate Maxwell's centroids in school-aged children (7 to 14 years) with and without dyslexia. More specifically, the study sought to compare the characteristics of Maxwell's centroids between the dominant and non-dominant eyes within each group and to examine potential relationships involving asymmetry between the two eyes.

Methods

Participants

Twenty-nine students aged 7 to 14 years participated in this study. Of these, 17 participants were diagnosed with dyslexia ("dyslexia group") and 12 participants had not reported learning disabilities ("control group"). Participants with dyslexia were required to have a formal diagnosis of dyslexia established by a multidisciplinary team (i.e., speech therapist, psychologist, ophthalmologists or neurologists, among others). To be included in the control group, participants could not present any report suggestive of learning disabilities. Participants with dyslexia were recruited from centers dedicated to the treatment of phonological difficulties, whereas control participants were recruited through contact with the local community.

The study was conducted in accordance with the guidelines of the local Ethics Committee (CAAE: 19418419.7.0000.5465). All procedures were performed with the appropriate understanding and written informed consent of the participants' legal guardians.

Procedures

Participants completed a single experimental session. Each participant sat facing a device and placed one eye at a viewing tube mounted on a table (Figure 1). Through the central aperture of this tube, they viewed a white screen positioned 3 m ahead. Inside the tube, a structure housed two optical filters, a blue filter (OD 6 Fluorescent Filter, Edmund Optics) and a green filter (Hard Coated OD 4.0, 25 nm Bandpass Filter, Edmund Optics), that were manually alternated by the experimenter using a lever. Moving the lever upward or downward allowed the participant to view the screen through either the blue or the green filter, respectively.

The filters used in this study were the same type used in the protocol described by Le Floch and Ropars (2017), which we replicated. This procedure corresponds to the foveascopy technique, and the images produced are referred to as "Maxwell's centroids". The blue fluorescent filter transmitted light centered at 450 nm (bandwidth 20 nm), whereas the green band-pass filter transmitted light centered at 534 nm (bandwidth 25 nm).

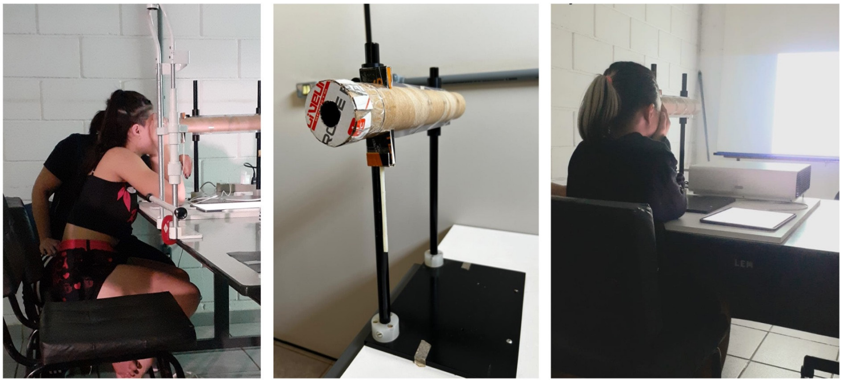

Figure 1. Ilustrative pictures of a participant's position facing the device (left), the device used in the experiment (center), and an overall view showing the screen placed ahead and the tablet positioned next to the participant (right).

Participants were instructed to identify a dark spot that appeared on the screen while the experimenter alternated the filters every 5 s. After perceiving the image, they reproduced what they saw on a tablet (iPad Pro 12.5", 5th generation, Apple Inc.) using a digital pencil (Apple Pencil, 2nd generation, Apple Inc.). The procedure was then repeated for the other eye. All reproduced images were recorded and stored directly on the tablet.

After completing the reproduction task, each participant performed the hole-in-the-card test to determine ocular dominance. For this test, participants held a 20 × 25 cm card with a 6 mm central hole (Barbeito, 1981) at arm's length, keeping both eyes open. They aligned the hole with a fixation point located 6 m ahead and were instructed not to move the card. The experimenter then alternately occluded each eye and the dominant eye was identified as the eye that maintained alignment with the fixation point through the hole in the card (Seijas *et al.*, 2007).

Data analysis

The images stored on the tablet were transferred to a computer while preserving their pixel dimensions. A custom program developed in LabVIEW (National Instruments, Inc.) was used to manually trace the contour of each participant's reproduced image for each eye using a mouse. Before outlining, a calibration procedure was performed to convert pixel measurements to centimeters based on three reference points whose distances were measured and digitized. During the contour tracing, the horizontal (x) and vertical (y) coordinates of the cursor were recorded at a sampling rate of 20 points per second.

The recorded coordinates were plotted as scatter data, and a circular fit was applied using the least-squares method. This procedure yielded the radius (r) of the best-fit circle for each outlined image. The area (A) and circumference (C) were then calculated as: $A = \pi r^2$ and $C = 2\pi r$. The resulting measurements were saved in ASCII files separately for each eye and each participant in the dyslexia and control groups. Following, a custom MATLAB routine (MathWorks, Inc.) was used to estimate the ellipse parameters of each reproduced image (Gal, 2003), for both dominant and non-dominant eyes. This procedure followed the methodology described by Le Floch and Ropars (2017).

Asymmetry of the Maxwell's centroids was quantified as the ratio between the minor (AB) and major (CD) axes of the ellipse. Specifically, asymmetry values were calculated as AC/BD for images corresponding to each participant's dominant ($\varepsilon_D = AC/BD$) and non-dominant ($\varepsilon_{ND} = AC/BD$) eyes. The asymmetry coefficient was then obtained by subtracting these values ($\Delta\varepsilon = \varepsilon_D - \varepsilon_{ND}$). Positive values of $\Delta\varepsilon$ indicate greater asymmetry in the dominant eye, negative values indicate greater asymmetry in the non-dominant eye, and values near zero indicate minimal or no asymmetry (Le Floch & Ropars, 2017).

After all these procedures, the variables obtained and analyzed in this study included the area, radius, and circumference of the Maxwell's centroid images for each eye, as well as the asymmetry coefficient for participants in both groups.

Statistical analysis

To examine similarities in age, body mass, height, and body mass index (BMI) between participants with and without dyslexia, both univariate (ANOVA) and multivariate (MANOVA) analyses of variance were conducted with group (dyslexia and control) as the independent factor. Age was included as the dependent variable in the ANOVA, whereas body mass, height, and BMI were included as dependent variables in the MANOVA.

Because the area and circumference variables did not meet the assumption of normality, data transformations were applied following Field (2009): a base-10 logarithmic transformation for area and a square-root transformation for circumference. After transformation, both variables satisfied the normality requirement, and ANOVAs were subsequently performed.

To assess potential differences in the characteristics of Maxwell's centroids, ANOVAs were conducted with group and eye (dominant and non-dominant) as factors, with repeated measures on the eye factor. Separate ANOVAs were performed for area, radius, and circumference as the dependent variables. To examine potential asymmetry between the dominant and non-dominant eyes, an additional ANOVA was performed with group as the factor and the asymmetry coefficient as the dependent variable.

All analyses were conducted using the Statistical Package for the Social Sciences (SPSS). The significance level was set at 0.05 for all tests.

Results

From the 29 participants assessed in the study, two from the dyslexic group and one from the control group reported that they did not see the Maxwell's centroids and were excluded from the final analysis. Table 1 presents the general information of the final sample, according to the group. The ANOVA did not reveal any group effect regarding age ($F_{1,24}$=1.42, *p*=0.245), neither MANOVA regarding body mass, height, and body mass index (Wilks'Lambda=0.97, $F_{3,21}$=0.21, *p*=0.889).

Table 1. Means and standard deviations for age, body mass, and height, and number of participants for sex and eye dominance in the dyslexia and control groups.

Characteristic	Dyslexic group (n=15)	Control group (n=11)
Age (years)*	10.7 ± 2.1	11.6 ± 1.6
Body mass (kg)*	47.9 ± 21.4	43.8 ± 17.3
Height (m)*	1.48 ± 0.16	1.48 ± 0.12
Sex (female/male)	10/5	10/1
Eye dominance		
Right	n=8	n=8
Left	n=6	n=3
Non-dominance	n=1	n=0

Figure 2 illustrates images reproduced by four participants from the dyslexia and control groups using their dominant and non-dominant eyes. This figure highlights the variability in what each participant perceived with each eye and subsequently reproduced the Maxwell's centroid spots.

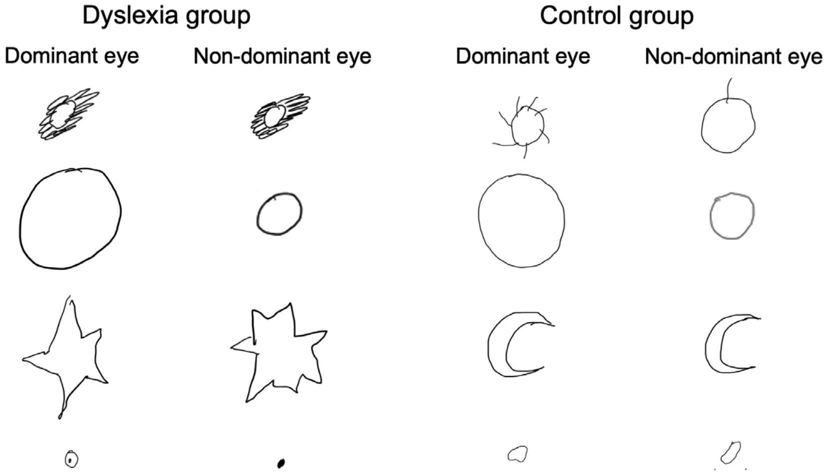

Figure 2. Examples of the Maxwell's centroid images reproduced by four participants in the dyslexic (left) and control (right) groups using their dominant and non-dominant eyes.

Figure 3 shows the boxplots for the interquartile range, median, and mean values of area, radius, and circumference from the images of Maxwell's centroids reproduced by participants in the dyslexia and control groups. The ANOVA for area revealed a group effect ($F_{1,24}$=4.48, p=0.045), but no eye effect ($F_{1,24}$=1.03, p=0.320) and no group and eye interaction ($F_{1,24}$=0.29, p=0.591). The dyslexia group exhibited larger area compared to the control group (Figure 3A).

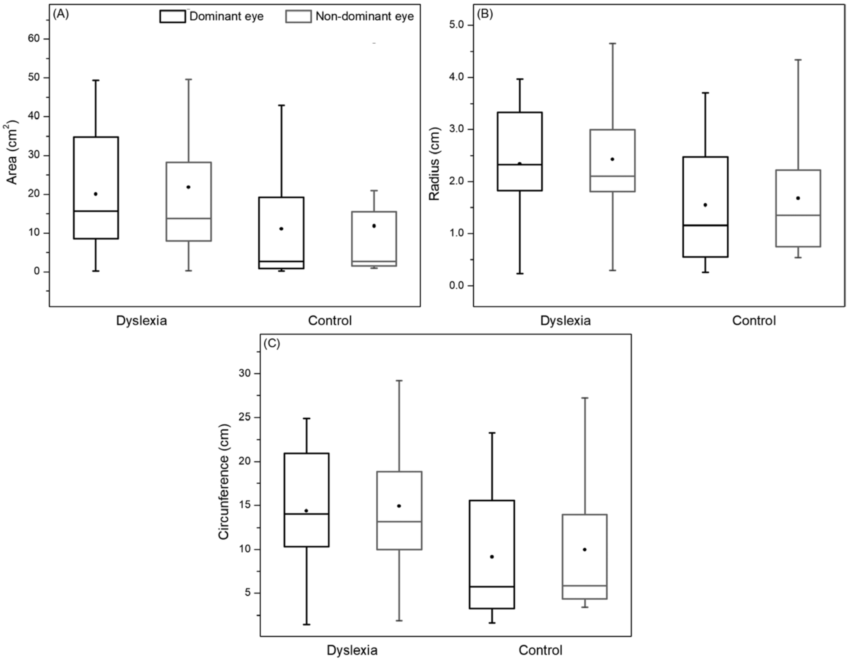

Figure 3. Area (A), radius (B), and circumference (C) values from the Maxwell's centroid images reproduced by participants in the dyslexia and control groups for the dominant (black) and non-dominant (gray) eyes. The boxplots show the median, interquartile range, and the full range (maximum to minimum), and the black dot denotes the mean.

The ANOVA for radius revealed a group effect ($F_{1,24}$=4.28, *p*=0.049), but no eye effect ($F_{1,24}$=0.19, *p*=0.666) and no group and eye interaction ($F_{1,24}$=0.01, *p*=0.916). The dyslexia group presented larger radius compared to the control group (Figure 3B). Finally, the ANOVA for circumference revealed a group effect ($F_{1,24}$=4.71, *p*=0.040), but no eye effect ($F_{1,24}$=0.46, *p*=0.502) and no group and eye interaction ($F_{1,24}$=0.090, *p*=0.764). The dyslexia group presented longer circumference compared to the control group (Figure 3C).

Figure 4 shows the individual asymmetry coefficient values, with each participant's eye dominance also indicated. It is important to note that one participant from the dyslexia group did not present eye dominance. As we had taken into consideration dominant and non-dominant eyes in the data analysis, for this participant specifically, we had considered the right eye as “dominant”. As shown in Figure 4 A and 4B, there was no apparent relationship between the tested eye dominance and the calculated asymmetry.

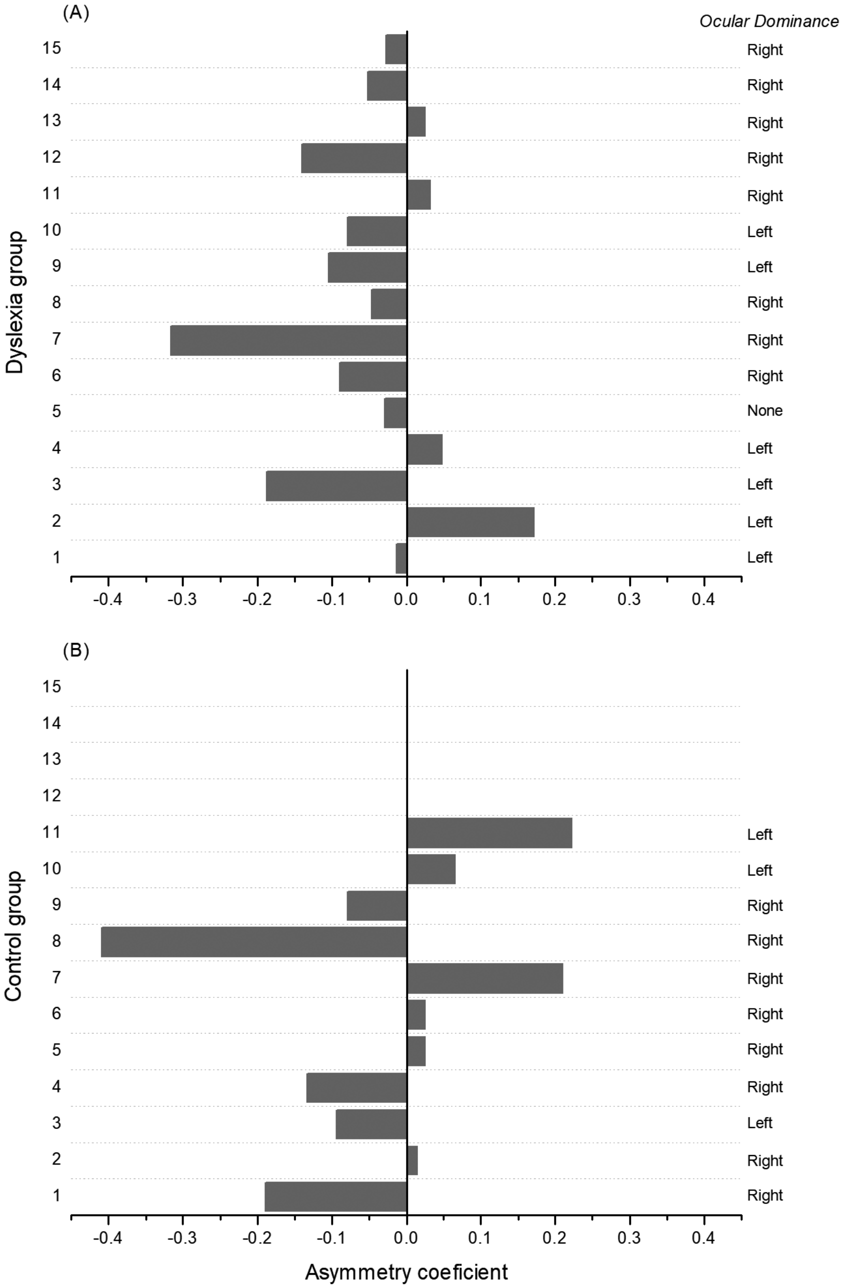

Figure 4. Individual asymmetry coefficient values from the Maxwell's centroid images reproduced by participants in the dyslexia and control groups, with each participant's eye dominance indicated.

Figure 5 shows the boxplots for the interquartile range, median, and mean values of asymmetry coefficient from the images of Maxwell's centroids reproduced by participants in the dyslexia and control groups. The ANOVA revealed no group effect ($F_{1,24}$=1.04, p=0.318).

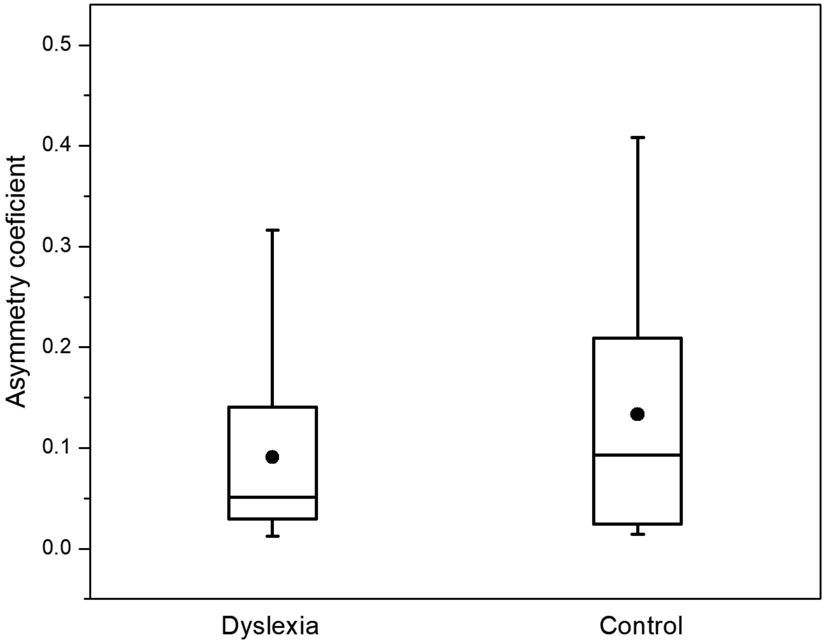

Figure 5. Individual asymmetry coefficient values from the Maxwell's centroid images reproduced by participants in the dyslexia and control groups. The boxplots show the median, interquartile range, and the full range (maximum to minimum), and the black dot denotes the mean.

Discussion

The aim of this study was to investigate the characteristics of Maxwell's centroids in students aged 7 to 14 years, with and without dyslexia, and to examine whether there is a relationship in asymmetry between the dominant and non-dominant eyes in these students. Overall, participants in the dyslexia group exhibited larger area, greater radius, and greater circumference of the reproduced Maxwell's centroid images compared to participants in the control group. On the other hand, the asymmetry coefficient of these centroids between the dominant and non-dominant eyes was similar across both groups.

Unlike the study by Le Floch and Ropars (2017), which reported that adults reproduced images with circular or elliptical shapes, the participants in the present study reproduced images with varied shapes (Figure 2). More specifically, our participants reproduced images resembling a diffuse spot, an expanded shell, a star, a ring, a ring with a central spot, a distorted ring resembling a crescent moon, or a ring with a dark peripheral halo. It is important to note that the shapes observed in our study are similar to those reported by Chen and colleagues (2015). Previous studies have also reported Maxwell's centroids reproduced as a dark ring or an expanded shell (Miles, 1953), or as a diffuse dark spot, a star with a central dark spot, a dark ring without a central spot, or a dark ring with a central dark spot (Isobe & Motokawa, 1955). Thus, the varied shapes reproduced by participants in the present study may be related to individual differences in the distribution of macular pigment within the fovea (Chen *et al.*, 2015).

Le Floch and Ropars (2017) associated the symmetry of Maxwell's centroids with the absence of ocular dominance in individuals with dyslexia. The results of the present study revealed the presence of asymmetry in Maxwell's centroids and ocular dominance in both dyslexia and control groups. Considering that those investigators suggested that the nervous system has difficulty processing visual information from both eyes in individuals with dyslexia (Le Floch & Ropars, 2017), such an explanation does not appear to apply to students between 7 and 14 years old.

In this study, students with dyslexia not only exhibited asymmetry in Maxwell's centroids but also reproduced images that were notably larger than those of the control group. These results lead us to question whether this magnification perceived by children with dyslexia is related to the distribution of red and blue cones in the fovea (Isobe, 1955), to a steeper and narrower foveal pit (Chen *et al.*, 2015), or perhaps whether the increased radius of Maxwell's centroids is associated with the spatial density of macular pigment distribution (Misson *et al.*, 2023). It is likely that individuals with dyslexia present a different macular structure. However, this possibility needs to be investigated in future studies using optical coherence tomography to assess foveolar dimensions and foveal rim geometry, as performed in previous work (Chen *et al.*, 2015), or through examinations that detect macular pigment density and distribution, such as non-mydriatic fundus photography, like that employed by Misson and colleagues (2023).

In summary, the results of this study indicate that students with dyslexia aged 7 to 14 years show Maxwell's centroid characteristics similar to those students without dyslexia, but with larger magnitude. The characteristics of these centroids were similar between the dominant and non-dominant eyes for both groups. Finally, there was no relationship in asymmetry between the dominant and non-dominant eyes for most participants in either group. Thus, the results of the present study differ from those reported by Le Floch and Ropars (2017), likely due to differences in macular pigment density or foveal pit geometry between individuals under 15 years old and adults.

Acknowledgments

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