

# Proprioceptive intervention positively affects visual attention of children with dyslexia after 21 months

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## Abstract

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Abnormal eye patterns and poor visual attention are often exhibited by children with dyslexia while performing reading and fixation tasks. Recently, many intervention programs, such as oculomotor exercises and visual attentional training have been tested to help attenuate or mitigate these difficulties. In the present study, our objective was to investigate the effects of the proprioceptive intervention in dyslexic children performing a fixation task. Our hypothesis was that children

with the proprioceptive intervention would present better visual attention than dyslexic children only with a regular orthophonic intervention and equal results to a healthy control group. The proprioceptive intervention (which involves the use of prism glasses, oral neurostimulation, insoles and breathing exercises) was administered for 21.2 months (SD: 14.7), superimposed on a regular orthophonic intervention, for a group of 12 dyslexic children. Two other groups participated in this study: 20 dyslexic children with only the orthophonic intervention and 20 healthy children. All three groups (52 children) performed a basic fixation task (fixate a cross target in the middle of a fully white screen). Our results validated the initial hypothesis. Indeed, they showed that children with the proprioceptive intervention presented blink and saccade number and pupil dilation equivalent to healthy children; and that the dyslexic children only with the orthophonic intervention required higher blink and saccade number and pupil dilation than both other groups. Overall, the proprioceptive intervention had a positive impact on lowering cognitive workload in dyslexic children, thus showing a promising solution to reduce ocular difficulties in dyslexia.

## **Introduction**

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Children with developmental dyslexia often present several literacy difficulties, that vary in type and severity, including phonological and reading deficits: fluency, accuracy and comprehension (Richlan, 2020). Problems at the level of phonological representation and literacy skills often persist into adulthood, despite the access to a proper educational environment (Snowling, Hulme & Nation, 2020). It is well established that children with dyslexia exhibit abnormal eye

movement patterns, i. e. significant more fixations of longer duration and significant more frequent saccades with smaller amplitude than typical children in fixation, saccadic and simple reading tasks (Bucci *et al.*, 2024; Bucci *et al.*, 2018). In addition, these children also present significant more blinks and greater pupil dilation during reading, which is tied to a heavier cognitive load, concentration and visual attention to perform the same task than healthy children (Ozeri-Rotstain *et al.*, 2020; Tooze, 2022). To help understand and overcome these difficulties, several strategies have been tested, such as visual training or adaptations to reading materials.

Bucci *et al.* (2018) conducted an oculomotor training with four exercises (rapid naming task, Stroop task, motion perception and saccades) for 8 weeks (15 minutes, 5-7 days a week) with infants with dyslexia. They found that infants with dyslexia exhibited a significant decrease in total reading time and fixation duration after such a training. Caldani *et al.* (2020) tested a 10-minute visual attentional training (pursuit, saccade and searching tasks) after a control reading task and before the experimental reading task. The results showed that the 10-minute visual attentional training helped infants with dyslexia to significantly decrease their total reading time, fixation duration and saccade number (in the second reading task in contrast to the first one). In terms of blinking and pupil size, Wang (2019) tested the efficiency of an E-learning environment for dyslexia. Students with dyslexia performed three reading tasks, with a visual and motivational training of 5-10 minutes between each task. Students with dyslexia presented a significant decrease in blink number and increased pupil size after the training in comparison to healthy students, meaning students with dyslexia became more concentrated and engaged in the learning process after the training session.

Another type of intervention that has shown promising results is the proprioceptive intervention, which is primarily aimed at correcting sensorimotor impairments. The proprioceptive intervention involves ocular correction with the use of prism glasses, and other strategies such as postural treatment, oral neurostimulation, use of insoles and breathing exercises (Quercia *et al.*, 2007). Virlet *et al.* (2024) administered this proprioceptive intervention to dyslexic children for 9 months, with a minimum of 25 sessions, each lasting half an hour. In this study, the dyslexic patients attended a medical appointment to adjust the prism and insoles and learn the breathing exercises, and then they only had to perform this exercises 10 minutes each morning, in addition to their regular orthophonic intervention. In Virlet *et al.* (2024), the authors tested the influence of the proprioceptive intervention in addition to the regular orthophonic intervention for reading performance in dyslexic children. The study showed i) equivalent reading performance between healthy children and dyslexic children performing both orthophonic and proprioceptive interventions and ii) significantly better reading performance in both previous groups than in dyslexic children who were not treated with the proprioceptive intervention. This previous study have shown a positive significant effect on the proprioceptive intervention in improving reading skills. However, to the best of our knowledge, no study has investigated the effects of the proprioceptive intervention on eye movements and visual/cognitive load in children with dyslexia.

In the present study, our objective was to test the effects of a proprioceptive intervention on eye movements and visual attention in dyslexic children. We tested three groups: i) children treated with the proprioceptive intervention in addition to a regular orthophonic intervention; ii) children treated only the orthophonic intervention; and iii) typical children, as a control

group. The children performed a basic fixation task, in which they had to fixate the gaze on a black target in the middle of a white screen. Our main hypothesis was that children with the proprioceptive and orthophonic interventions would i) present significantly less demand for visual attention (less blinks, decreased pupil dilation) and eye movements closer to normal (less fixations with smaller duration, less saccades with larger amplitude) than the children only with the orthophonic intervention and ii) equivalent results to the control group.

## Methods

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### Participants

G\*power was used to calculate the required sample size for detecting a main effect of group between dyslexic and healthy children. Based on the results published by Sacaklıdır *et al.* (2025) (who performed a stationary gaze task on firm surface, as in our study), and using a t-test for independent sample, the power analysis determined that approximately 28 participants are needed to achieve 80% power at an alpha level of 0.05.

The present study included three groups (n = 52): dyslexic children with proprioceptive and orthophonic intervention (POI group, n = 12, 7 boys, 5 girls, mean age 145.16 months old); dyslexic children only with orthophonic intervention (OI group, n = 20, 7 boys, 13 girls, mean age 132.35 months old); and healthy control children (CO group, n = 20, 15 boys, 5 girls, mean age 142.05 months old).

For the inclusion criteria, all participants had to be native French-speakers, who attended the French educational system, and were between 9-13 years old. They also had a labile vertical

heterophony at the proprioceptive Maddox test, and normal or corrected-to-normal vision (wore glasses, contact lenses). Children with dyslexia were asked to bring their medical diagnose report to confirm their dyslexic condition and, at the day of the study, had to score higher than 2 standard deviations at the C-index of the Alouette-R test. For the non-inclusion criteria, children in the dyslexic groups should not have any neurodevelopmental issues (other than dyslexia), and healthy children should not have any neurodevelopmental issues nor proprioceptive dysfunction. Children in all groups should not have medical issues for standing balance nor psychiatric conditions. Furthermore, all children should have an optic correction (if required) lower than  $\pm 0.75$  dioptries and could not show any pathological score at the Parinaud (P2) test (for close vision).

A written informed consent form was signed by participants and their parents before the experiment, which was approved by the Regional Ethical Committee NoSyDys (n°2020\_1460).

## **Experimental tasks**

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### **Apparatus**

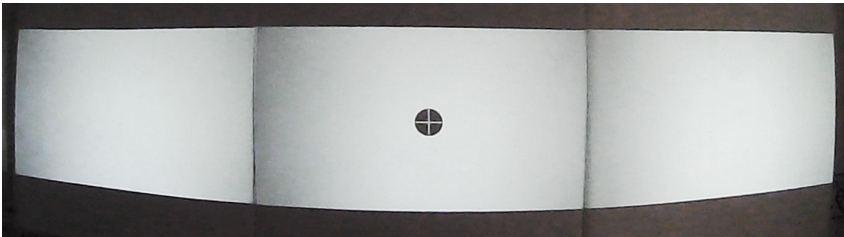
In order to project the fixation task, three video projectors (Philips NeoPix Easy 2+, resolution of 1280×720 pixels) were used. Together, they projected a single image (3840×768 pixels) onto a white panoramic screen (3m wide and 1m high). An eye-tracking system (Pupil Labs CORE, Berlin, Germany, consisting of two infrared cameras with 192×192 pixels of resolution, acquisition frequency of 240 Hz) was used to collect ocular data.

A main computer running MATLAB (MathWorks Inc., Natick, MA, USA, 2010; version 7.10.0; R2010a) was used with a customized

script to present the task, record the trials, collect the data and process all the systems.

## Task and instructions

The experiment consisted of a basic fixation task (Figure 1), with two trials of 30 sec of duration. To complete the task, the children had to fixate the gaze on a black target (size:  $3^\circ$  diameter) projected in the middle of a full white screen (composed of three panels measuring 1 m left-right and 60 cm up-down each). Children were standing in a comfortable, relaxed position, with their arms on the side of their bodies. The whole experiment had a total time of approximately 20 minutes.



**Figure 1.** Representation of the basic fixation task.

## Procedures

The lights in the room where the experiment took place were turned off. As they arrived, the children were equipped with the eye-tracking glasses. They were positioned at a viewing distance of 2.14 m from the screen, with a visual angle of  $70^\circ$  left-right and  $16^\circ$  up-down. The eye-tracking was calibrated and then the child proceeded to perform both trials in the fixation task, provided that they could rest as long as they needed between the trials.

## **Dependent variables**

Number of blinks and pupil size were used as measures of visual attention, as they often determine areas of interest and suggest more or less efficiency in visual activities (Mahanama *et al.*, 2022). In fact, greater pupil dilation and lower blinking rate indicate a heavier cognitive load while performing certain activities. Thus, blinks were detected by a rapid closing and reopening of the eyelid, when the pupil was obscured and then becomes visible again. In turn, the pupil size was obtained with a cleansing signal method using linear interpolation and Hanning window smoothing after removing blinks and other events. From that, we calculated the mean pupil size and the mean pupil diameter change (MPDC).

For eye movements, the eye-tracker collected the number and duration of fixations. A dispersion threshold was used to detect the fixations, considering the degrees of visual angle with a minimum duration of 100 ms. The fixation duration was obtained considering the difference between the initial timestamps of consecutive fixations with the subtraction of the saccade interval. Saccades were not directly provided by the eye-tracker, so a Python script was employed to detect them. The script is based on the Identification Velocity-Threshold (I-VT) algorithm (Andersson *et al.*, 2017) and it calculates the velocity between each gaze point at each timestamp. The velocity should be higher than  $45^\circ/\text{s}$  and the amplitude higher than  $0.65^\circ$  (the size of the center of the target used in the tasks) to be counted as an unwanted saccade.

## **Statistical analyses**

Outliers, that is, extreme values that were two standard deviations outside the quartiles were identified for all the

variables prior to the statistical analysis (Tabachnik & Fidell, 2006, pp. 76–77, 92, 100).

Shapiro-Wilk tests revealed that the data for saccade number and amplitude and blinks did not comply with normality assumptions, and were then transformed using natural log. After that, we conducted our statistical analyses using ANOVAs (with the basic fixation task and the three groups of participants as factors for each of the dependent variables). When necessary, Holm-Bonferroni post-hoc tests were used. All analyses were performed at the level of significance at 0.05. All the statistical analyses were conducted with JASP 0.19.3 package.

## Results

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### Outliers

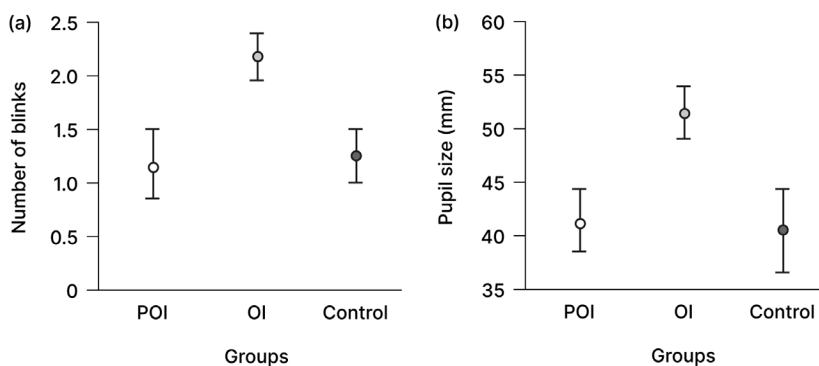
We identified 0.86% outliers for group OI, 1% for group CO, and 1.25% for group POI in the ocular data. These outliers were not considered for statistical analyses.

### Visual attention and eye movements

#### Number of blinks and pupil size

Figure 2 shows number of blinks and pupil size for all three groups (POI, OI and CO). In terms of number of blinks, ANOVA showed a significant effect of group ( $F(2, 49) = 7.08, p = 0.002$ ). Post hoc tests showed that OI had significantly higher number of blinks than CO ( $p = 0.004$ ) and POI ( $p = 0.01$ ). ANOVA did not show significant group and visual task interaction ( $F(2, 49) = 0.49, p = 0.61$ ; Fig. 2a). For pupil size, ANOVA showed a significant effect of group ( $F(2, 22) = 7.54, p = 0.003$ ). Post hoc tests showed that OI

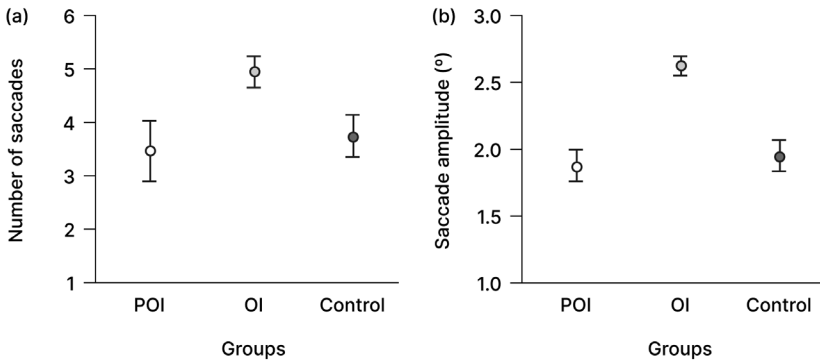
had significantly higher pupil size than the CO ( $p = 0.004$ ) and the POI ( $p = 0.016$ ). Finally, ANOVA did not show group and visual task interaction ( $F(2, 22) = 0.41, p = 0.66$ ; Fig. 2b).



**Figure 2.** Mean and standard deviation of number of blinks (a) and pupil size (b) for the proprioceptive and orthophonic intervention (POI), orthophonic intervention (OI) and control groups.

### Number and amplitude of saccades

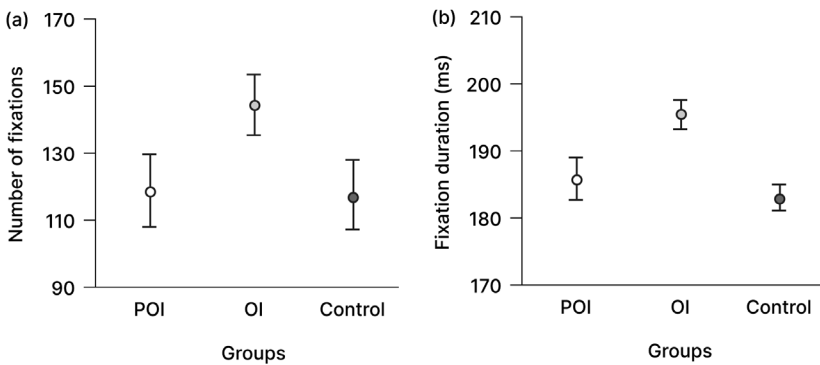
Figure 3 depicts number and amplitude of saccades for all three groups (POI, OI and CO). Regarding number of saccades, ANOVA showed a significant main effect of group ( $F(2, 49) = 3.79, p = 0.029$ ). Post-hoc tests showed that the OI group had significantly higher number of saccades than the CO ( $p = 0.04$ ). However, ANOVA did not show group and visual task interaction ( $F(2, 49) = 0.83, p = 0.44$ ; Fig. 3a). For saccade amplitude, ANOVA showed a significant effect of group ( $F(2, 49) = 5.76, p = 0.006$ ). Post hoc tests showed that OI had significantly larger saccade amplitude than CO ( $p = 0.009$ ) and POI ( $p = 0.027$ ). However, ANOVA did not show group and visual task interaction ( $F(2, 49) = 0.71, p = 0.49$ ; Fig. 3b).



**Figure 3.** Mean and standard deviation of number (a) and amplitude (b) of saccades for the proprioceptive and orthophonic intervention (POI), orthophonic intervention (OI) and control groups.

### Number and duration of fixations

Figure 4 depicts number and duration of fixations for all three groups (POI, OI and CO). For number of fixations, ANOVA did not show a significant effect of group,  $F(2, 49) = 0.74$ ,  $p = 0.48$ , nor group and visual task interaction,  $F(2, 49) = 0.05$ ,  $p = 0.95$  (Fig. 4a). Also, for fixation duration, ANOVA did not show a significant effect of group,  $F(2, 49) = 2.13$ ,  $p = 0.12$ , nor group and visual task interaction,  $F(2, 49) = 0.07$ ,  $p = 0.92$  (Fig. 4b).



**Figure 4.** Mean and standard deviation of number (a) and duration (b) of fixations for the proprioceptive and orthophonic intervention (POI), orthophonic intervention (OI) and control groups.

## Discussion

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In the present study, we aimed to test the effects of the proprioceptive intervention on eye movements and visual attention of children with dyslexia. Our results showed that the POI group presented significantly less blinks, reduced pupil size, decreased number and amplitude of saccades than the OI group, and that these measures were also equivalent to the CO group.

### **Proprioceptive intervention leads to better visual attention**

Our hypothesis was that children in the POI group would i) present significantly less demand for visual attention (less blinks, decreased pupil dilation) than the OI group and ii) equivalent results to the control group. Our results validated that hypothesis. Firstly, the POI group exhibited significantly less blinks (Figure 2a) and significantly reduced pupil size (Figure 2b) than the OI group. Consistent with the literature, our results showed that children in the POI group required less cognitive and visual attention to perform the fixation task than the OI group. In fact, in the literature reports, blink rate is recognized as an indicator of workload (Wang, 2019; Ozeri-Rotstain *et al.*, 2020). Our results with blink rates were in line with Wang's (2019) findings, whom reported decreased blink number in dyslexic children during reading after a visual and motivational training.

Secondly, and also as expected, the POI group showed significantly lower pupil dilation than the OI group (Figure 2b). Pupil diameter usually increases with the cognitive load required to perform certain activities, and is also connected to fatigue, stress and motivation levels (Le Cunff, Dommett and Giampietro, 2023). The novelty in our study was to demonstrate that the proprioceptive intervention can cancel the dyslexic-related

impairment in pupil behavior found in a fixation task. Other studies showed that dyslexic students could increase pupil size after a motivational training when performing reading tasks, meaning they became more concentrated (Wang, 2019). Altogether, all these results show that training and/or proprioceptive intervention can favor an improvement in cognitive load.

Overall, our results showed that the POI group performed the fixation task as the CO group and better than the OI group in considering blinks and pupil size. Normally, fewer attentional resources are available in children with dyslexia when they are exposed and process a particular visual stimulus (Kristjánsson and Sigurdardóttir, 2023). Hence, our results confirmed the beneficial effects of the proprioceptive intervention in reducing cognitive workload and need for high visual attention in dyslexic children. To the best of our knowledge, these patterns of results with blink and pupil size contrasting groups with/without the proprioceptive intervention and a control group are novel in the literature.

### **Saccade number closer to normal with the proprioceptive intervention**

Our hypothesis was that children in the POI group would i) exhibit eye movements closer to normal (less fixations with smaller duration, less saccades with larger amplitude) than the OI group and ii) equivalent results to the control group. Our results validated our hypothesis only for saccade number. In fact, regarding eye movements, our results indeed showed that the POI group exhibited significantly fewer number of saccades (Figure 3a) and smaller saccade amplitude (Figure 3b) than the OI group and equivalent ones to the CO group. In terms of number

of saccades, our results were consistent with Caldani *et al.* (2020) who reported significant difference in saccade number for a reading task after a visual attentional training. Barela *et al.* (2020) also found a significant decrease in saccade number, using both a fixation task and a visually-guided eye movement task.

In terms of saccade amplitude, we are not aware of any published study showing similar result in a fixation task. Virlet *et al.* (2024) reported larger saccade amplitude in dyslexic children after a proprioceptive intervention but their dyslexic and healthy children performed a reading task and not a fixation one. The contrast between our results and Virlet *et al.*'s (2024) might be explained by the fact that reading and non-reading tasks depend on different brain regions and mechanisms (such as the dorsal visual pathway, which plays a crucial role in visual attention and eye movements) (Kristjánsson and Sigurdardóttir, 2023). Variations in the magnocellular input may cause differences in attentional processing during reading and other types of visual stimuli. The novelty in our study was to find that the proprioceptive intervention also had some positive effects in eye movements in tasks other than reading: i.e. fixation task.

### **Limitations, opening and conclusion**

A first limitation in the present study concerns the sample size. Our results would have been more generalizable if we had included a larger sample, with participants more evenly distributed between groups (with and without proprioceptive intervention). In addition, it could be interesting to include a more diverse sample, with different age ranges, levels of literacy, languages and/or cultural contexts (Coenen *et al.*, 2024). A second limitation is that we transformed some of our data using natural log to comply with normality assumptions. Better it is at

the statistical level if a future research can validate our results again without any data transformation.

For recall, our main results show that the POI group exhibited less cognitive workload, visual attention and saccade number than the OI group and equivalent results to the CO group in performing a basic fixation task. These findings indicate that, after a proprioceptive intervention of 21 months, the dyslexic children were able to significantly improve their eye movements (saccade number) and visual attention (blinks and pupil size). We should mention that, by itself, the proprioceptive intervention is not demanding and/or constraining as it only requires the patient to attend one medical appointment to adjust prism glasses and insoles and receive instructions on how to perform the breathing exercises. Then, the dyslexic patient only has to perform breathing exercises 10 minutes a day each morning and attend their classical orthophonic intervention appointments (once a week, in general). Our findings thus show beneficial effects of the proprioceptive intervention to approach dyslexia visual impairments.

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