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Influence of both cutaneous input from the foot soles and visual information on the control of postural stability in dyslexic children.

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Highlights

This study brings evidence that:

- Postural parameters are significantly greater in dyslexic children with respect to non-dyslexic children.
- Postural parameters change depending to visual or postural condition.
- RQ is significantly smaller in dyslexic children and it depends to postural conditions.

Abstract

Dyslexic children show impaired in postural stability. The aim of our study was to test the influence of foot soles and visual information on the postural control of dyslexic children, compared to non-dyslexic children. Postural stability was evaluated with TechnoConcept® platform in twenty-four dyslexic children (mean age: 9.3 ± 0.29 years) and in twenty-four non-dyslexic children, gender- and age-matched, in two postural conditions (with and without foam: a 4-mm foam was put under their feet or not) and in two visual conditions (eyes open

and eyes closed). We measured the surface area, the length and the mean velocity of the center of pressure (CoP). Moreover, we calculated the Romberg Quotient (RQ). Our results showed that the surface area, length and mean velocity of the CoP were significantly greater in the dyslexic children compared to the non-dyslexic children, particularly with foam and eyes closed. Furthermore, the RQ was significantly smaller in the dyslexic children and significantly greater without foam than with foam. All these findings suggest that dyslexic children are not able to compensate with other available inputs when sensorial inputs are less informative (with foam, or eyes closed), which results in poor postural stability. We suggest that the impairment of the cerebellar integration of all the sensorial inputs is responsible for the postural deficits observed in dyslexic children.

Key words: Dyslexic children, Somesthesic input, Visual input, Postural control, Cerebellar integration, Romberg Quotient.

1. Introduction

Dyslexia is a neurological disorder characterized by a delay in the ability to read, write and learn. This delay is independent of social, education, intelligence or motivation levels (American Psychiatric Association, 2013)[1].

Postural stability must be maintained efficiently in everyday life and is controlled by several sensory inputs[2]. Frank and Levinson, in 1973[3], were the first to suggest a cerebellar-vestibular impairment in dyslexics. These authors examined 115 children with dyslexia and found that 97% of them showed neurological signs of cerebellar-vestibular deficiency evidenced by a positive Romberg test, difficulties in tandem walking, articulatory speech disorders, hypotonia and several disymetric deficits (finger-to-nose, heel-to-toe, writing and drawing)[3]. Neuroimaging studies[4-5] reported a smaller volume of the right anterior lobe of the cerebellum

and biochemical differences in the temporo-parietal lobe among dyslexic people compared to healthy subjects. These results are in line with the cerebellar hypothesis deficit previously reported by Nicolson and Fawcett[6].

Other authors also observed balance and motor coordination impairment[7] in children with dyslexia and hypothesized that dyslexia is characterized by a cerebellar deficit. Indeed, postural instability in dyslexic children was similar to that observed in children with cerebellar deficit, suggesting a poor sensory multimodal integration by the cerebellum in these children. Previously, Patel *et al.* (2010)[8] evaluated postural control in dyslexic adults under different conditions (on foam or firm surfaces, with eyes closed or open). They reported that the instability observed in dyslexic subjects was in keeping with the severity of their dyslexic disorders: postural sway was greatest among the subjects with the highest clinical dyslexic signs. In the same study these authors explored the postural control of healthy adults, on foam and with decreased cutaneous inputs due to hypothermic anesthesia. They reported that foam yielded more perturbation on postural control than hypothermia did. Interestingly, an impairment of the postural stability of healthy younger adults with an experimentally-induced loss of sensitivity of their cutaneous foot soles (ischemic blocking) has also been described. Such impairment was significantly stronger in difficult conditions (eyes closed and on narrow supports), suggesting that the sensitivity of cutaneous foot soles leads to poor postural stability, especially when there is no visual information[9].

Several studies[10-17] reported poor postural control in dyslexic children. We will report below studies exploring the effect of changing sensory inputs (visual and/or cutaneous input from the foot soles) in the control of postural sway within a dyslexic population. While involved in a postural task in which somesthesic and visual inputs were modified (the children were asked

to stay on one foot and close their eyes) the dyslexic children proved to be more unstable than the control children, particularly when they were standing on one foot (right or left) and when their eyes were closed. In such unstable conditions, somesthesic and visual inputs are respectively reduced or missing, and the increased postural sway in such situations suggests the important role they play in the control of posture. Since dyslexic children reported poor postural stability, we can hypothesize that they are not able to use compensatory strategies with other sensorial inputs; this could be due to their difficulties to integrate multimodal sensory information *via* the cerebellum[18]. Postural control in dyslexic children with or without prismatic and sole correction and in control children, after applying vibration ankle stimulation in order to alter somesthesic information, showed that with vibration on the ankle the length and mean velocity of the CoP were significantly greater among the dyslexic children without treatment (prism and sole correction) than in both the dyslexic children with treatment and the control children. Moreover, without vibration on the ankle there was no difference between postural performance among the dyslexic children with treatment and the control children. Consequently, the authors reported that integration of somesthesic inputs for controlling postural stability is lacking in dyslexic children. Nevertheless, they suggested that this impairment could be improved by treatments (prism and sole correction)[19]. Furthermore, the dyslexic children showed a significantly greater postural sway than the control children in a disturbed visual condition (a moving room oscillating backward and forward)[20]. although visual inputs were equally involved in postural control in the two groups of children, the dyslexic children showed a poorer performance at controlling their stability. Thus, the authors suggested that a lack of automaticity could be at the origin of the poor postural stability observed in dyslexic children[20]. In a recent study from our team[17], we showed (using wavelet analysis) that dyslexic children found it difficult to use all the sensory inputs available to them, most likely due to a poor cerebellar integration activity[21].

Based on all these findings the present study aims to explore further how dyslexic children use sensory inputs to control their postural stability, and how they can compensate changes in sensory information in disturbing conditions (with or without foam and with visual input). We also evaluated their Romberg Quotient (RQ) in order to explore further the role of visual sensorial inputs on postural control in dyslexic children.

2. Material and method

2.1 Subjects

Twenty-four dyslexic children aged from 6.9 to 11.7 (mean age: 9.35 ± 0.29 years) and twenty-four non-dyslexic, gender- and age-matched children (mean age: 9.23 ± 0.36 years) participated in the study. The children did not have any drug treatment or orthopedic anomaly, and were recruited from a pediatric hospital to which they had been referred for a complete evaluation of their dyslexia, including their neurological, psychological and phonological capabilities. The time needed to read a text was assessed for each child, as well as the children's general comprehension of the text, and their ability to read words and pseudo-words using the L2MA battery[22]. This is the standard test developed by the Centre de Psychologie Appliquée de Paris, often used in France and already implemented to select dyslexic subjects in our previous studies. The inclusion criterion was: a normal mean intelligence quotient (IQ, evaluated with WISC-IV; between 85 and 115). The range of the neurological examination performed on all the children enrolled in the study was normal and the children were naive of psychotropic treatment. None of them had a personal history of vestibular or visual deficit or neurological or psychiatric disorders. In France, children are considered to be dyslexic when their reading capabilities are delayed at least beyond 1.5 standard deviations with respect to age-matched children. The mean IQ and the mean reading age were 103 ± 1.1 and 7.4 ± 0.2 years, respectively. The chronological age, reading age, IQ

and reading age difference for the dyslexic and non-dyslexic children are shown in Table 1. Healthy children came from the families of the hospital staff or volunteers and were recruited after a routine examination. The investigation adhered to the principles of the Declaration of Helsinki and was approved by our Institutional Human Experimentation Committee. Written consent was obtained from the children's parents after an explanation of the experimental procedure was provided.

2.2 Material

2.2.1 Platform

A platform (principle of strain gauge) consisting of two dynamometric clogs (Standards by Association Française de Posturologie 1985-1986, produced by TechnoConcept®, Céreste, France) was used to measure postural stability.

The position of the feet was the following: on the footprints, heels distant by 3 cm and feet spread out in a symmetrical way with respect to the sagittal axis of the child at a 30° angle. Arms were placed vertically along the body. The displacement of the center of pressure (CoP) was measured for 25.6 seconds; signals from the force platform were recorded at a frequency of 40 Hz (16-bit analog-digital resolution). The platform took into account the weight, waist and foot size of each child to record his/her postural sway.

2.2.2 Experimental paradigm

Easy and identical instructions were given to each child. The children had to stay as stable and relaxed as possible on the platform, with their feet on the footprints and their arms along their bodies. In the eyes open condition (EO) the children had to look at a red dot, 200 cm in front of them, while in the eyes closed condition (EC) both eyes were closed by a patch. In the condition with foam (-F-), in order to increase change sensory input from the foot soles, a 4-

mm of foam was placed on the platform footprints. Indeed, according to several studies [23-27] the use of such foam perturbs the reliability of somatosensory input from cutaneous mechanoreceptors of the foot sole. Due to low thickness, foam did not involve a change in motor activity. Previous study reported that standing on a foam surface increased the difficulty to maintain postural control and modified the postural parameters[8-9].

Three trials were run for each of these conditions (EO and EC with and without foam). The order of the conditions was random.

2.2.3 Postural recordings

We analyzed the surface area, the length and the mean speed of the center of pressure (CoP). These postural parameters are representative parameters of the variability of the CoP in space and allow for efficient measurement of CoP spatial variability. The surface area of the CoP corresponds to an ellipse with 90% of CoP excursions[28]. The length of the CoP is the path of the center of pressure. The mean velocity of the CoP is the CoP displacements over the sampled period, that is, the sum of the displacement scalars over the sampling period divided by the sampling time. It yields a good index of the amount of neuromuscular activity required to regulate postural control[28-29]. The Romberg Quotient (RQ), *i.e.* the ratio between the surface area of the CoP with eyes closed and eyes open, was calculated in the two postural conditions (with and without foam)[31].

2.3 Statistical analysis

Mixed-design multivariate analysis of variance (MANOVA) tests were conducted to analyze the differences between the two groups of children. Furthermore, in order to explore the effect of the different conditions (with and without foam; eyes closed and eyes open) on postural

parameters, statistical analyses with repeated measures (ANOVA) were performed (as in previous studies [16; 28-29]). Statistica software was used with the GLM (General Linear Models) in both groups of children (dyslexic and non-dyslexic children) as inter-children factors and postural parameters (surface area, length, main velocity of the CoP and RQ) as dependent variables. *Post-hoc* comparisons were made with the Fischer's test (LSD). The effect of a factor was considered significant when the p-value was below 0.05.

3. Results

First, a correlation was established between the severity of the dyslexic disorders and the surface area of the CoP. We did not find any significant correlation (both $p > 0.17$).

Figure 1 shows the surface area (mm^2) of the CoP for dyslexic and non-dyslexic children in each condition tested (eyes open and eyes closed, with and without foam, EO, EC, EO-F and EC-F, respectively). ANOVA showed a significant effect of group ($F_{(1,48)} = 3.96$, $p<0.05$). LSD test showed that the surface area of the CoP of dyslexic children was significantly greater than that of the non-dyslexic children ($p<0.05$). ANOVA also showed a significant effect of the postural conditions ($F_{(1,48)} = 5.58$, $p<0.02$); the surface area of the CoP was significantly greater in the postural condition with foam than without foam ($p<0.02$). Then, ANOVA showed a significant effect of the visual conditions ($F_{(1,48)} = 12.44$, $p<0.01$), as the surface area of the CoP was significantly greater with eyes closed than with eyes open ($p<0.01$). ANOVA did not reporte a significant interaction between group, postural condition and visual condition ($F_{(1,48)} = 0.12$, $p=0.73$).

Figure 2 shows the length (mm) of the CoP for the dyslexic and non-dyslexic children in each condition tested (eyes open and eyes closed, without and with foam under the feet, EO, EC,

EO-F and EC-F, respectively). ANOVA showed a significant effect of group ($F_{(1,48)}$ = 4.60, $p<0.04$): the dyslexic children had a significantly longer CoP than the non-dyslexic children ($p<0.04$). ANOVA also showed a significant effect of postural condition ($F_{(1,48)}$ = 7.67, $p<0.01$): the CoP was significantly longer in the postural condition with foam than in the without foam condition ($p<0.01$). Last, ANOVA showed a significant effect of visual condition ($F_{(1,48)}$ = 13.89, $p<0.01$): the CoP was significantly longer with eyes closed than with eyes open($p<0.01$). ANOVA failed to reporte a significant interaction between group, postural condition and visual condition ($F_{(1,48)}$ = 2.04, p=0.16).

Figure 3 shows the mean velocity (mm/s) of the CoP for dyslexic and non-dyslexic children in each condition tested (eyes open and eyes closed, without and with foam under the feet, EO, EC, EO-F and EC-F, respectively). ANOVA showed a significant effect of group ($F_{(1,48)}$ = 4.33, $p<0.04$): the dyslexic children had a significantly greater mean velocity of the CoP than the non-dyslexic children ($p<0.04$). ANOVA also showed a significant effect of postural condition ($F_{(1,48)}$ = 12.96, $p<0.01$): the mean velocity of the CoP was significantly greater in the postural condition with foam than in the without foam condition ($p<0.01$). Last, ANOVA showed a significant effect of visual condition ($F_{(1,48)}$ = 11.74, $p<0.01$): the mean velocity of the CoP was significantly greater with eyes closed than with eyes open ($p<0.01$). ANOVA did not report a significant interaction between group, postural condition and visual condition ($F_{(1,48)}$ = 0.94, p=0.34).

Figure 4 shows the Romberg Quotient for the dyslexic and non-dyslexic children with and without foam. ANOVA showed a significant effect of group ($F_{(1,48)}$ = 3.79, $p<0.05$): the RQ was significantly smaller among the dyslexic children than among the non-dyslexic children

($p<0.05$). ANOVA also showed a significant effect of postural condition ($F_{(1,48)} = 3.89$, $p<0.05$): the RQ value decreased significantly with foam compared to without foam ($p<0.05$).

4. Discussion

The main findings of this study are as follows: (i) the oscillations of the CoP are significantly greater among dyslexic children than non-dyslexic children; (ii) the surface area, length and mean velocity of the CoP change depending on the visual or postural conditions; (iii) RQ is significantly smaller in dyslexic children and depends on postural conditions. Based on these findings, we suggested that poor postural control in dyslexic children is due to cerebellar deficits; (iv) cerebellar impairment in dyslexic children could lead to poor postural control.

These findings are discussed individually below.

(i) the oscillations of the CoP are significantly greater in dyslexic children than in non-dyslexic children

Our current findings showed that dyslexic children have a significantly greater surface area, length and mean velocity of the CoP than non-dyslexic children. These findings are in keeping with previous studies on dyslexic children. As has been extensively described in the literature, dyslexic children are more unstable than non-dyslexic children[3;6-7;10-12;14-17;19-20].

(ii) Surface area, length and mean velocity of the CoP change depending on visual or postural conditions

In the present study, the postural parameters (surface area, length and mean velocity of the CoP) change depending on the conditions; all these parameters increased significantly when the children had foam under their feet, or their eyes closed. This finding suggests the important role played by both the cutaneous foot soles input and visual information in postural control.

Several studies we already mentioned showed a poor postural control among dyslexic children when the postural conditions are more difficult (staying on one foot, vibration on the ankle or moving support)[16-18]. Our study showed that a thin foam of only 4 mm changed postural sways, most likely because of the ability to compensate the disturbed or decreased sensory cutaneous input from the foot soles, in keeping with the hypothesis of a deficiency of cerebellar integration among dyslexic children[4-5;7;21]

Moreover, the present study also showed that dyslexic children were more unstable in the absence of vision, which is in line with several other studies[10-12; 14;17;21]

(*iii) RQ is significantly smaller in dyslexic children and depends on postural condition.*

In the current study the RQ is significantly smaller among the dyslexic children than among the non-dyslexic children, in keeping with the fact that dyslexic children are more unstable than non-dyslexic children under both eyes open or eyes closed conditions. Such results are in line with postural disabilities extensively known in dyslexic children showed by our group[15-17] and other researchers[19-20]. Another important finding is that the RQ decreased significantly with foam under the feet of the children – and this occurred among the dyslexic as well as the non-dyslexic children. These results are in favor of deficits in the use of visual inputs among the dyslexic children compared to the non-dyslexic children. Moreover, the fact that the foam

disturbed the RQ could be in line with the fact that the cutaneous inputs of the foot soles can involve a change in the integration of visual inputs.

Several studies[32-33] showed that adults with disorders (vestibular and visual disorders, respectively) are able to compensate their sensorial deficits by enhancing other inputs in order to obtain a good postural stability. The authors suggested that when one sensory input is deficient or less available, the other subsystems compensate such impairment by playing a more important role. Consequently, we could hypothesize that the decreased cutaneous inputs from the foot soles caused by the foam yield a poorer postural control due to a deficit in weighting the other available inputs. Importantly, note that this occurs for both dyslexic and non-dyslexic children. Interestingly, a study by Mohapatra (2014)[34] reported that foam placed under the feet of healthy young adults resulted in a specific feedback and feedforward on their postural control, characterized by an early activation of their anterior muscles and a greater muscular activity. Consequently, regardless of these specific feedbacks and feedforwards induced by the foam, we suggested that foam disturbs the weighting and use of the other sensory inputs available.

(*iv) The cerebellar impairment in dyslexic children could lead to poor postural control*

The ability to use compensatory strategies involves the capacity to weight sensory inputs depending on environment perturbations thanks to cerebellar integration. Widely described in the literature, the dyslexia-linked deficits involve cerebellar capabilities[4-5;7;18;21]. A study described similar postural instability both in dyslexic children and in children with cerebellar lesions[31]. Moreover, neurophysiological studies, described a difference in the left temporo-parietal lobe and right cerebellum in dyslexics compared to healthy adults[4]. Furthermore, a smaller right anterior lobe of the cerebellum as well as a smaller global brain volume have been reported in dyslexics[5]. The cerebellum could be one of the most significant locations for

structural differences between dyslexic and non-dyslexic children in line with the cerebellar deficit hypothesis in dyslexia[21].

From a clinical point of view, the application of these results suggests training for dyslexic children so that they can use their sensory inputs better. A study reported[36] that performing a specific training program (motor exercises done daily at home) allowed young children (3 years old), to improve their capacity of motor control as well as their cognitive abilities. Other studies involving subjects without dyslexic disorders will be necessary to confirm such finding. For example, Katz-Leurer[37] described that children with cerebral palsy or post-traumatic brain injury improved their postural performance after some postural training (one minute each day, five days per week). Patients with cerebellar degeneration improved postural sway after postural training. The authors, using structural magnetic resonance imaging, described that such improvements were due to an increase of gray matter volume in the dorsal pre-motor cortex[38]. Moreover, a study reported that using a treadmill 8 minutes per day allowed a better development of walking onset (step, stability) in younger children with risk of motor delay[39]. All these studies, which do not only involve the dyslexic population, show that postural exercises are relevant to improve body stability and are in favor of brain plasticity.

5. Conclusion

Finally, we would like to point out that our current findings show that a change in the cutaneous input from the foot soles and/or in visual information are responsible of poor postural control in children and that such impairment is more obvious in dyslexic children, most likely due to their inability to compensate and/or reweigh the sensory system *via*

cerebellar integration. Moreover, the use of visual inputs by dyslexic children could be disturbed by a change in somesthesic input integration. Further research is needed to explore their ability to weigh sensory inputs by cerebellum adaptation.

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Conflict of Interest

The authors declare that no conflicting interests exist.

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Figures' legends

Figure 1: Means and standard errors of the surface area (mm²) of the CoP for dyslexic and non-dyslexic children in each condition: eyes open and eyes closed, without and with foam under their feet (EO, EC, EO-F and EC-F, respectively).

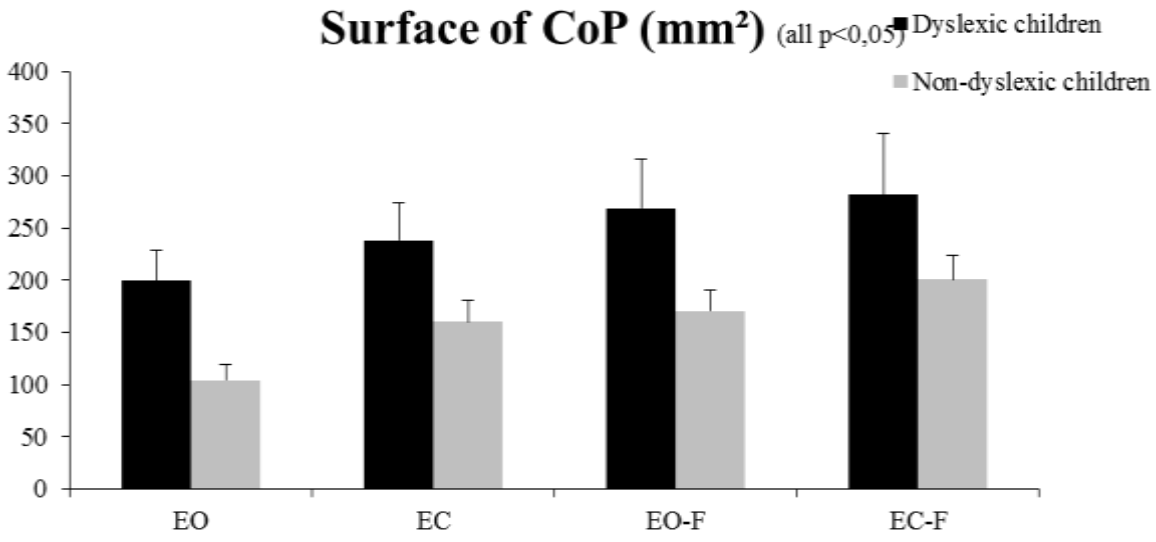

Figure 2: Means and standard errors of the length (mm) of the CoP for dyslexic and non-dyslexic children in each condition: eyes open and eyes closed, without and with foam under their feet (EO, EC, EO-F and EC-F, respectively).

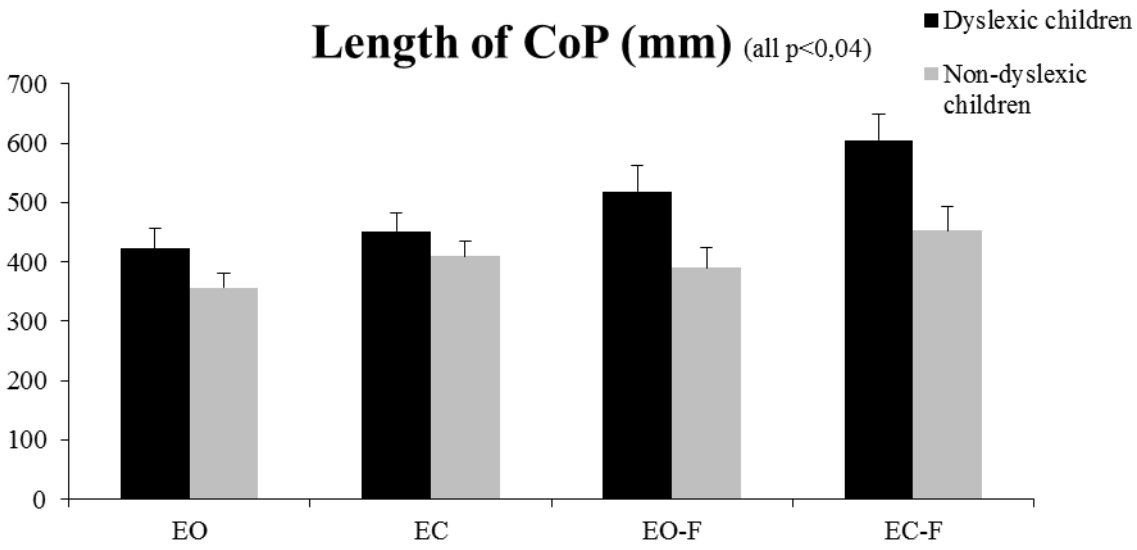

Figure 3: Means and standard errors of the mean velocity (mm/s) of the CoP for dyslexic and non-dyslexic children in each condition: eyes open and eyes closed, without and with foam under their feet (EO, EC, EO-F and EC-F, respectively).

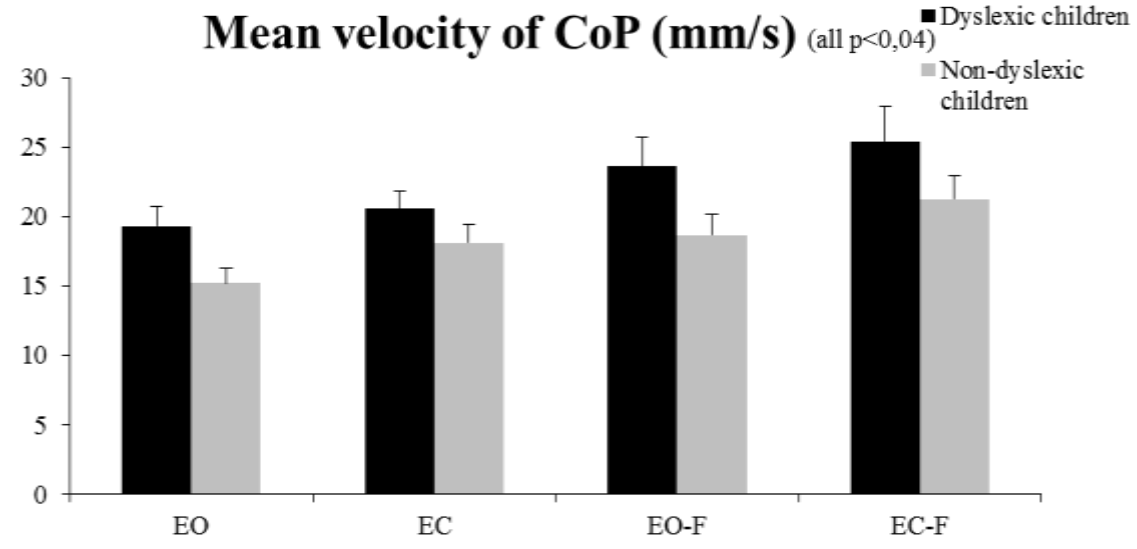

Figure 4: Mean and standard errors of the Romberg Quotient without and with foam under the feet of the dyslexic and non-dyslexic children

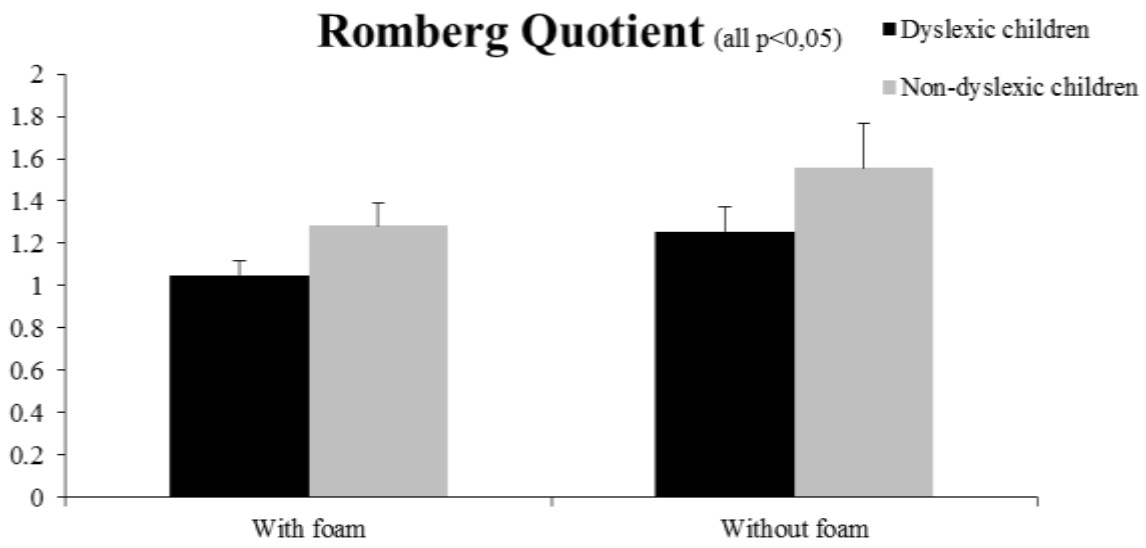

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Table 1: Mean and standard error of chronological age, reading age and IQ for dyslexic and non-dyslexic children.

	Dyslexic children			**Non-dyslexic children**			
	Chronological age (years)	**Reading age (years)**	**IQ**	**Chronological age (years)**	**Reading age (years)**	**IQ**	**Reading age difference (years)**
	7,5	6	96	6,2	6,2	82	1,5
	7,5	6	109	6,8	6,8	48	1,5
	7,6	6	85	6,9	6,9	49	1,6
	7,7	6,2	89	7,2	7,2	52	1,5
	7,9	6,4	103	7,3	7,3	94	1,5
	8	6	108	7,5	7,5	95	2
	8,4	7	87	7,9	7,9	99	1,4
	8,6	6,5	102	8,2	8,2	104	2,1
	8,6	6,8	97	8,3	8,3	113	1,8
	8,7	6,5	105	8,8	8,8	68	2,2
	8,8	6,5	100	8,8	8,8	110	2,3
	9	7	108	9	9	70	2
	9,25	7	95	9,3	9,3	73	2,25
	9,5	7,3	99	9,6	9,6	89	2,2
	9,9	7,5	110	9,8	9,8	118	2,4
	10,25	8,1	110	9,9	9,9	79	2,15
	10,3	8	85	10,4	10,4	124	2,3
	10,4	8,3	92	10,6	10,6	86	2,1
	10,5	8,4	87	10,7	10,7	127	2,1

	10,67	8,6	106	10,8	10,8	88	2,07
	10,8	8,5	110	11,4	11,4	134	2,3
	11,2	9,4	105	11,6	11,6	105	1,8
	11,7	9,8	98	11,9	11,9	99	1,9
	12	10	100	12,6	12,6	106	2
Mean	**9,36**	**7,41**	**99,42**	**9,23**	**9,23**	**92.17**	**1,96**
Standard error	**0,28**	**0,25**	**1,72**	**0,36**	**0,36**	**4,89**	**0,06**