Clinical Neurophysiology xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Spatial and temporal analysis of postural control in dyslexic children

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ARTICLE INFO

Article history:
Accepted 9 October 2014
Available online xxxx

Keywords:
Dyslexia
Children
Postural control
Wavelet transformation
Sensorial strategy
Cerebellum

HIGHLIGHTS

- Spatial and temporal analysis demonstrated that dyslexic children have poor postural control.
- For both groups, postural control is condition-dependent improves when the eyes are open on stable platform.
- Dyslexic children have postural spectral indices higher and cancelling time shorter than non-dyslexic children.

ABSTRACT

Objective: The aim of this study is to examine postural control of dyslexic children using both spatial and temporal analysis.
Methods: Thirty dyslexic (mean age 9.7 ± 0.3 years) and thirty non-dyslexic age-matched children participated in the study. Postural stability was evaluated using Multitest Equilibre from Framiral®. Posture was recorded in the following conditions: eyes open fixating a target (EO) and eyes closed (EC) on stable (-S-) and unstable (-U-) platforms.
Results: The findings of this study showed poor postural stability in dyslexic children with respect to the non-dyslexic children group, as demonstrated by both spatial and temporal analysis. In both groups of children postural control depends on the condition, and improves when the eyes are open on a stable platform. Dyslexic children have spectral indices that are higher than in non-dyslexic children and they showed a shorter cancelling time.
Conclusion: Poor postural control in dyslexic children could be due to a deficit in using sensory information most likely caused by impairment in cerebellar activity.
Significance: The reliability of brain activation patterns, namely in using sensory input and cerebellar activity may explain the deficit in postural control in dyslexic children.

1. Introduction

Postural control involves an intricate relationship between sensory information and motor activity (Lacour and Borel, 1993). In everyday life, quiet standing is a rather simple postural task that is regulated automatically by subcortical nervous structures and spinal motoneuronal pools (Massion, 1994). Dyslexia is a neurobiological disorder characterized by a difficulty in reading acquisition despite adequate intelligence, conventional education and motivation (American Psychiatric Association, 1994). Multisensory feedback serves to regulate posture control by continuously updating the internal model of the body's position, and this model in turn generates motor commands responding to the environmental context and to any constraints (Mergner and Rosemeier, 1998). Fawcett and Nicolson (1999) have argued that dyslexic children could have abnormal cerebellar functions such as skill automatisation, time estimation, balance and other cerebellar signs of dystonia. Moe-Nilssen et al. (2003) have shown that dyslexic children have an impairment of both balance and gait capabilities. According to Barela et al. (2003), the dyslexic children's impairment in the ability to learn, write and perform other tasks such as hold postural control is due to a cerebellar deficit.

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http://dx.doi.org/10.1016/j.clinph.2014.10.016
1388-2457/

Maintaining postural control is based on the central integration of multisensory inputs vestibular, visual and proprioceptive information. Thus, the ability to perceive our environment though the peripheral sensory system correctly allows us to have postural stability (Brandt, 2003). Konczak et al. (2005) have shown a similarity between children with cerebellar deficit and dyslexic children: poor postural stability reported in both these groups may be due to a difficulty to integrate multimodal sensory information to control their postural sway. Stoodley et al. (2005) have found that the balancing ability of dyslexic children standing on one foot was significantly worse than that observed in the control group of children. Moreover, Pozzo et al. (2006), comparing 50 dyslexic and 42 non-dyslexic age-matched children, have shown that dyslexic children have greater length, variability and mean power frequency of the center of pressure (CoP) displacements independently of the vision condition (eyes open or eyes closed). The authors have suggested that these postural parameters could be useful to discriminate dyslexia in children population. Vieira et al. (2009) have also reported impairment in postural stability when dyslexic children were doing a dual-task (reading single words silently).

Somesthesic information is also involved in postural control; Quercia et al. (2011) described postural capability after vibration stimulation in two groups of dyslexics (with and without prismatic postural treatment) and a group of non-dyslexic children. The authors showed that the length and mean velocity of the center of pressure increased significantly in dyslexic children without treatment with respect to dyslexics with treatment and the non-dyslexic group. Furthermore, in a condition without vibration stimulation, the postural stability was similar to that of the treated dyslexics and the non-dyslexic group. This study suggested that the integration of proprioceptive signals in postural stability is lacking in dyslexic children. Barela et al. (2011) suggested a deficit in automatic performance in dyslexia. These hypotheses are in line with the studies from our group (Legrand et al., 2012; Bucci et al., 2013), which have shown that dyslexic children are more unstable than non-dyslexic age-matched children in different types of dual tasks demanding different attention abilities (standing while making horizontal and vertical saccades, silently reading a text, or performing a Stroop task).

The use of nonlinear analysis methods such as the wavelet transformation method (Tinetti, 1986) and the stabilogram-diffusion analysis (Daubechies, 1991) for investigating posture control is well known. Such analysis reveals effects in the dynamic of the postural control system which are not shown by the more traditional posturography method based on spatial analysis only. A study from Ghulyan et al. (2005) demonstrated that dynamic analysis of posture allows better discrimination of pathological effects on postural control. Moreover, Lacour et al. (2008) described the limitations of the traditional posturography method, suggesting that the spatial analysis of the center of pressure could lead to misevaluations of the balance control system. They have supported the hypothesis of the usefulness and physiological relevance of the additional parameters provided by the wavelet analysis. Yelnik and Bonan (2008), in a study of an elderly patient suffering from a balance disorder, demonstrated that the main interest of temporal analysis is to gain an insight into the physiological and pathological mechanisms underlying postural stability impairment. As showed by Bernard Demanze et al. (2009) the use of wavelet transformation for exploring postural control is very relevant. Such analysis can reveal deficits or changes in the dynamics of postural control system which are not shown by the more traditional posturography done with static analysis.

Based on these findings, the present study aims to explore postural ability in dyslexic children using not only data analysis in the spatial domain (classical analysis used by the majority of researchers) but also temporal analysis (wavelet analysis), under different viewing conditions (eyes open and eyes closed), both on static and dynamic platforms. It remains to be tested whether postural deficits in dyslexic children could be better understood by using temporal analysis and whether this may give insight on the different types of sensorial information used by dyslexic children to control their posture.

2. Methods

2.1. Participants

Thirty dyslexic children (23 males and 7 females) aged 7.5–12.7 years, with a mean age 9.7 ± 0.3 years participated in the study with a selected age-matched control group of thirty non-dyslexic children (21 males and 9 females) aged 7.5–12.9 years with a mean age 9.9 ± 0.4 years. None of the children have drug treatment or orthopedic abnormality. Dyslexic children were recruited from a pediatric hospital to which they had been referred for a complete evaluation of their dyslexia with an extensive examination including neurological/psychological and phonological capabilities. For each child, we measured the time required to read a text passage, assessed general text comprehension, and evaluated the ability to read words and pseudo-words using the L2MA battery (Chevrie-Muller et al., 1997). This is the standard test developed by the Centre de Psychologie appliquée de Paris, often used in France and already employed in our previous studies for selecting dyslexic population (Bucci and Seassau, 2012; Bucci et al., 2013). Inclusion criteria were: scores of this test beyond 1.5 standard deviations; a normal mean intelligence quotient (IQ, evaluated with WISC-IV; between 85 and 115). In France, a child is considered to be dyslexic when her/his reading capabilities are delayed at least beyond 1.5 standard deviations with respect to reading-age matched children. Mean IQ was 103 ± 1.1 and the mean reading age was 7.4 ± 0.2 year. The non-dyslexic children had to fulfill the following criteria: no known neurological or psychiatric abnormalities, no history of reading difficulties, and no visual stress or difficulties with near or far vision. Reading measurements were also performed for these children; their scores for French (reading, comprehension and spelling), mathematics and foreign languages were all above the mean scores in their respective school grades.

An ophthalmological examination accompanied by orthoptic evaluation of visual functions was done (mean values shown in Table 1). Visual acuity was normal ($\geqslant$20/20) for all children in both groups. All children had normal binocular vision (60 s of arc or better), as evaluated with the TNO random dot test. In addition, an orthoptic evaluation of vergence fusion capability using prisms was carried out at far distance. The phoria (i.e., latent deviation of one eye when the other eye is covered, using the cover-uncover test) was within the normal range for all children tested (-4 pD and -2 pD in non-dyslexic and dyslexic children respectively). The convergence amplitude was significantly smaller in the dyslexic group than in the non-dyslexic group. An ANOVA showed a significant main effect of group ($F_{(1,57)} = 6.02$, $p < 0.02$) for convergence amplitude. In sum, the orthoptic evaluation showed poor vergence fusional capabilities in dyslexic children in line with other studies on this population (see Bucci and Seassau, 2012; Bucci et al., 2013) that could contribute to poor postural control reported in these children. Recall also that our group (Bucci et al., 2009) showed poor postural control in children without dyslexia with vergence abnormalities, consequently is important to know vergence capabilities in children before measuring posture.

The investigation adhered to the principles of the Declaration of Helsinki and was approved by our Institutional Human Experimentation Committee (Comite de Protection des Personnes CPP, Ile de France V, Hôpital Saint-Antoine). Written informed consent was

Table 1
Clinical characteristics of all children tested. Mean and standard deviation values for binocular vision (stereoacuity test, TNO measured in seconds of arc), near point of convergence (NPC measured in cm), vergence fusional amplitudes (convergence and divergence) in prism diopters measured at far distance and heterophoria at far distance, measured in prism diopters.

	TNO (s of arc)	NPC (cm)	Convergence (pD)	Divergence (pD)	Heterophorie (pD)
Dyslexic children	61 ± 2	4 ± 1	18 ± 2	5 ± 1	−1 ± 0.8
Non-dyslexic children	60 ± 4	2 ± 1	26 ± 3	17 ± 1	−1 ± 1

obtained from the children's parents after the nature of the procedure had been explained.

2.2. Material

Postural performances of children were evaluated using Multitest Equilibre also known as Balance Quest from Framiral® with static/dynamic platform by Micromedical Technologies (www.framiral.fr). It consisted of a force plate mounted on a translator, which allowed for a subject's translation in the antero-posterior (y) or medio-lateral direction (x). A computer-controlled mechanism allows the platform to make sinusoidal displacements of 62 mm amplitude with adjustable velocities and frequencies. The ramp mode allows forward and backward translations of the force plate, with constant linear velocities of 0.03 m/s and 0.07 m/s. For the sinusoidal mode, the frequency was 0.25 Hz. The CoP displacement was sampled at 40 Hz and 100 Hz in the static and dynamic conditions, respectively, and digitized with 16-bit precision (Ghulyan et al., 2005; Bernard Demanze et al., 2009).

2.3. Postural recording procedure

All children were in a dark room on the Framiral® platform. Each child was positioned on the platform; feet aligned parallel, on the footprints arms along the body and shoulder-width apart (between 10 and 32 cm). The platform was placed in a room large enough to prevent acoustic spatial orientation.

Recording was performed under four conditions. Two conditions on a stable platform (eyes open fixating a target, EO-S, and eyes closed, EC-S), and two conditions on an unstable platform (eyes open fixating a target EO-U and eyes closed EC-U). In the eyes open condition, the child had to fixate on a small red light at distance of 250 cm. The duration for each postural recording was 30 s with 15 s of rest between each condition to reduce possible fatigue effects. The order of the conditions varied randomly across children.

2.4. Classical data in the spatial domain

To quantify postural performance the surface area (cm^2) and the mean velocity (mm/s) of the CoP were analyzed (Fig. 1). The surface area of CoP is an efficient measure of CoP spatial variability, corresponding to an ellipse with 90% of CoP excursions (Chiari et al., 2002). The mean velocity of the CoP represents a good index of the amount of neuromuscular activity required to regulate postural control (Maki et al., 1990; Geurts et al., 1993). The mean velocity of the CoP is the mean velocity of the CoP displacements over the sampled period, that is, the sum of the displacement scalars over the sampling period divided by the sampling time. These two postural parameters allow efficient measurement of CoP spatial variability.

2.5. Frequency analysis

We also applied a wavelet analysis to study the frequency of the CoP displacements (Fig. 2). This analysis and associated parameters were obtained with the software from Framiral (www.framiral.fr, see Dumistrescu and Lacour, 2006; Bernard Demanze et al., 2009).

The spectral power index was calculated as the decimal logarithm for the frequency bands 0.05–0.5 Hz, 0.5–1.5 Hz, and higher than 1.5 Hz on the antero-posterior and medio-lateral sways (PIy and PIx, respectively). The spectral power index in the higher band is minimal in healthy subjects during quiet standing, but it can be observed with aging, in postural pathology or in dynamic postural conditions (Naschner, 1979). The hypothetical physiological significance of the different bands is as follows: 0–0.5 Hz visual–vestibular (Naschner, 1979; Kohen-Raz et al., 1996; Paillard et al., 2002), 0.5–1.5 Hz cerebellar (Paillard et al., 2002) and 1.5 Hz reflexive loops (Lacour et al., 2008; Bernard Demanze et al., 2009).

The cancelling time (CT) for each frequency band was also calculated for the antero-posterior (CTy) and medio-lateral (CTx) sway, i.e., the total time required to cancel the spectral power within a given frequency range by the posture control mechanisms; the longer the cancelling time for a frequency band, the

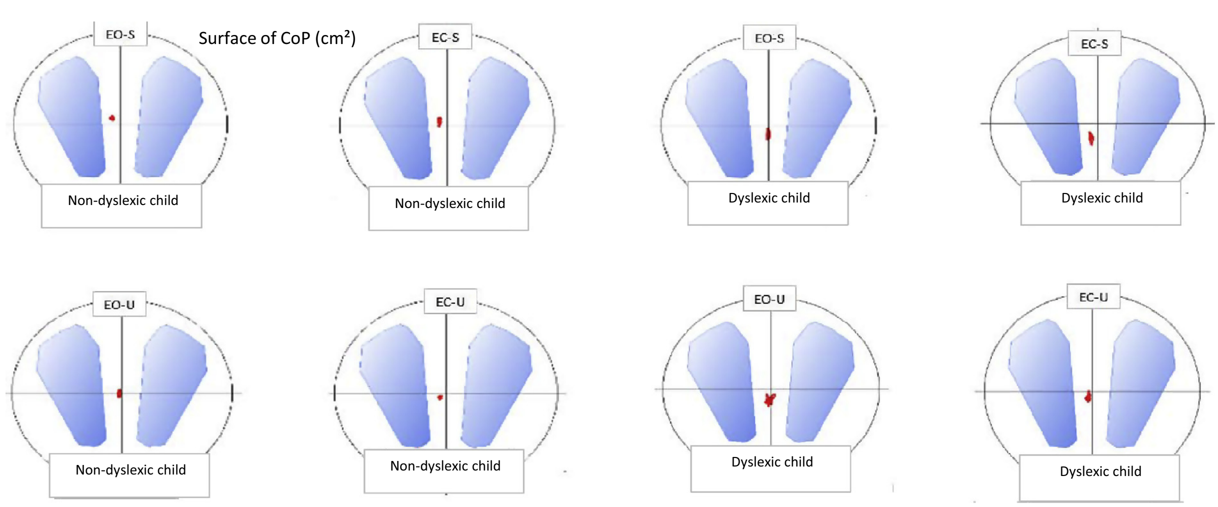

Fig. 1. Example of postural recording (surface of CoP in cm^2) in a non-dyslexic and a dyslexic child for the four conditions tested (EO-S, EC-S, EO-U and EC-U).

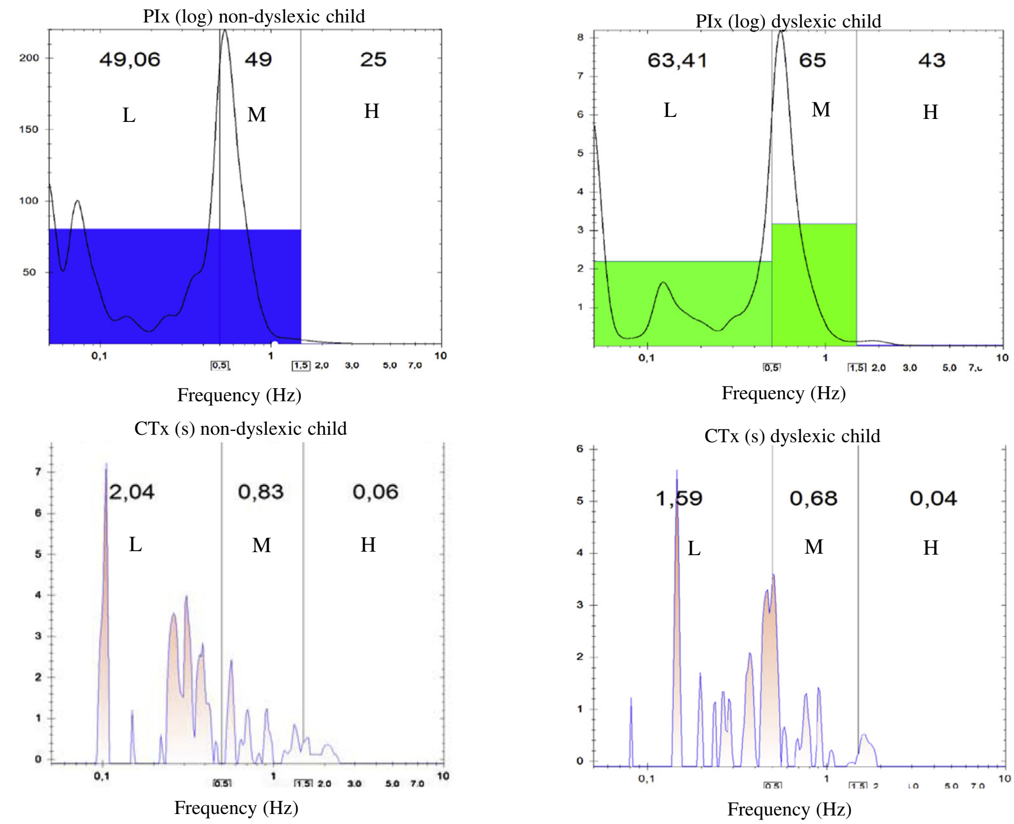

Fig. 2. Wavelet analysis of the CoP displacements: spectral power indices (log) and cancelling time (s) in medio-lateral direction, in a non-dyslexic and a dyslexic child.

better is the posture control (Dumistrescu and Lacour, 2006; Bernard Demanze et al., 2009). The cancelling time is the time required to use sensory inputs for controlling posture. The longer the time taken to achieve postural control, the more the children are using their sensory information (see Fig. 2).

A certain frequency with its power reduced to zero over a period of time indicates a successful action of the postural control system since the overall entropy of the sway has been reduced. While most healthy subjects exhibit these zero power instances in their postural sway spectrum, pathological subjects do not. How the cancelled frequencies are 'chosen' by the postural control system is not known, but it may be assumed that the choice criterion is the minimization of muscular effort required for controlling the sway (see review of Barge (2007)).

2.6. Statistical analysis

Statistical analysis was performed with the Statistica software using the GLM (Advanced Linear Models) using the two groups of children (dyslexic and non-dyslexic) as inter-subject factor, and postural parameters as within-subject factor. Post-hoc comparisons were made with the Fischer's test Least Significant Difference (LSD). The effect of a factor was considered significant when the p-value was below 0.05.

3. Results

3.1. Postural data in the spatial domain

3.1.1. Surface of CoP

Fig. 3 shows the surface area of CoP in all conditions tested for dyslexic and non-dyslexic children. The analysis of variance (ANOVA) shows a significant group effect ($F(1,57) = 8.40$, $p < 0.005$). Independently to the condition, the surface area of CoP in dyslexic children is significantly larger than non-dyslexic children ($p < 0.005$). ANOVA shows a significant effect of condition ($F(3,17) = 6.43$, $p < 0.001$). Independently of the group, the surface of CoP is greater in an unstable condition than in a stable condition. The surface area of the CoP in the eyes open and eyes closed on unstable support conditions are significantly greater than the surface area of the CoP in the eyes closed on stable support condition (both $p < 0.001$). ANOVA shows a significant effect of vision ($F(1,57) = 9.32$, $p < 0.001$). Independently of the group, the surface of CoP is greater in eyes closed conditions ($p < 0.001$). Analysis of variance (ANOVA) shows a significant interaction between group and condition ($F(3,17) = 5.69$, $p < 0.001$). The surface area of CoP in dyslexic children eyes open and eyes closed on unstable platform conditions is significantly greater than that reported on

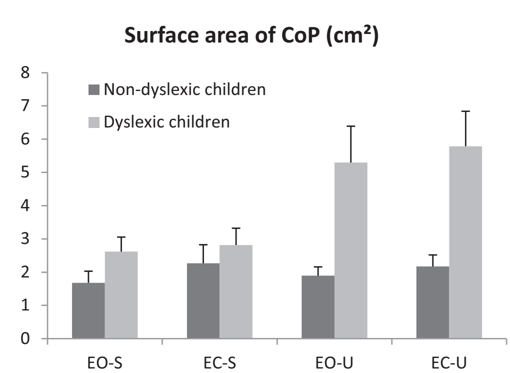

Fig. 3. Means and standard deviations of surface area of CoP in cm^2 in the two conditions (eyes open, EO and eyes closed EC) on stable -S- and unstable -U- platform for dyslexic and non-dyslexic children.

a stable platform and then those of non-dyslexic children in all conditions tested (all $p < 0.001$).

3.1.2. Mean velocity of CoP

Fig. 4 shows the mean velocity of CoP in all conditions tested for dyslexic and non-dyslexic children. Analysis of variance (ANOVA) shows a significant effect of group ($F_{(1,57)} = 7.28$, $p < 0.009$). Independently of the condition, in dyslexic children the mean velocity is significantly greater than non-dyslexic children ($p < 0.009$). Analysis of variance shows a significant effect of postural condition ($F(3,17) = 12.83$, $p < 0.001$). Independently of the group, mean velocity is significantly smaller in stable than in unstable condition. ANOVA shows a significant effect of vision ($F(1,57) = 6.15$, $p < 0.02$). Independently of the group, the mean velocity of CoP is greater in eyes closed conditions ($p < 0.02$). Mean velocity in eyes open on stable support condition is significantly smaller than the values in all other conditions (all $p < 0.005$). Moreover, mean velocity in eyes closed on stable support condition is significantly smaller than those in the two unstable conditions (eyes open and eyes closed, both $p < 0.04$).

Analysis of variance shows also a significant interaction between group and condition ($F_{(3,17)} = 3.19$, $p < 0.02$). The mean velocity of CoP, in dyslexic children, in two unstable conditions (eyes open and eyes closed) is significantly greater than that reported on stable platform and those of non-dyslexic children in all conditions tested (all $p < 0.001$).

3.2. Temporal analysis, wavelet transformation

3.2.1. Spectral power indices in antero-posterior and medio-lateral direction

Fig. 5 shows the spectral power indices in antero-posterior (PIy) and medio-lateral (PIx) direction in all four conditions tested for dyslexic and non-dyslexic children. Analysis of variance (ANOVA) shows a significant effect of group, for both directions: medio-lateral and antero-posterior, respectively ($F_{(1,57)} = 7.24$, $p < 0.009$) and ($F_{(1,57)} = 8.40$, $p < 0.005$). Independently of the conditions, for both directions (medio-lateral and antero-posterior) the spectral power indices are significantly greater in dyslexic than non-dyslexic children ($p < 0.009$). Analysis of variance (ANOVA) also shows a significant effect of frequency in both direction: medio-lateral and antero-posterior, respectively ($F_{(2,11)} = 2453$, $p < 0.001$) and ($F_{(2,11)} = 2487$, $p < 0.001$). Independently of group or condition, for both directions (medio-lateral and antero-posterior) spectral power indices for low frequency are significantly greater than that recorded in medium frequency which is significantly greater than that recorded in high frequency (both $p < 0.001$). Analysis of variance (ANOVA) shows a significant effect of postural condition ($F_{(3,17)} = 7.67$, $p < 0.001$). Independently of group, the spectral power index in medio-lateral is significantly smaller in stable (eyes open or eyes closed) than in unstable conditions (eyes open or eyes closed) (all $p < 0.001$). Analysis of variance (ANOVA) shows also a significant interaction between group, condition and frequency in both direction: medio-lateral and antero-posterior direction (respectively $F_{(6,34)} = 2.61$, $p < 0.02$ and $F_{(6,34)} = 2.27$, $p < 0.04$). The spectral power indices in both direction, in two unstable conditions (eyes open and eyes closed) are significantly greater in dyslexic children than in non-dyslexic children; this occurs for all frequencies (all $p < 0.01$). Moreover, in eyes closed on stable support condition, dyslexic children have a significantly greater spectral power index in antero-posterior in high frequency than non-dyslexic children ($p < 0.001$).

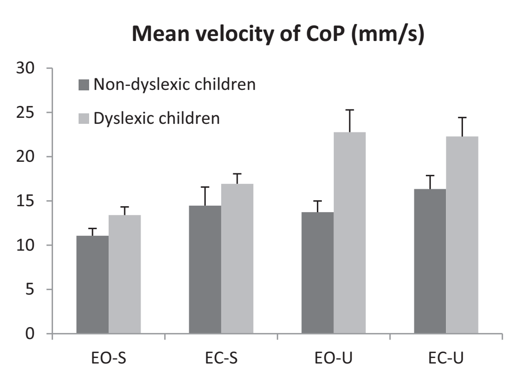

Fig. 4. Means and standard deviations of the mean velocity of CoP in mm/s in the two conditions (eyes open, EO and eyes closed EC) on stable -S- and unstable -U- platform for dyslexic and non-dyslexic children.

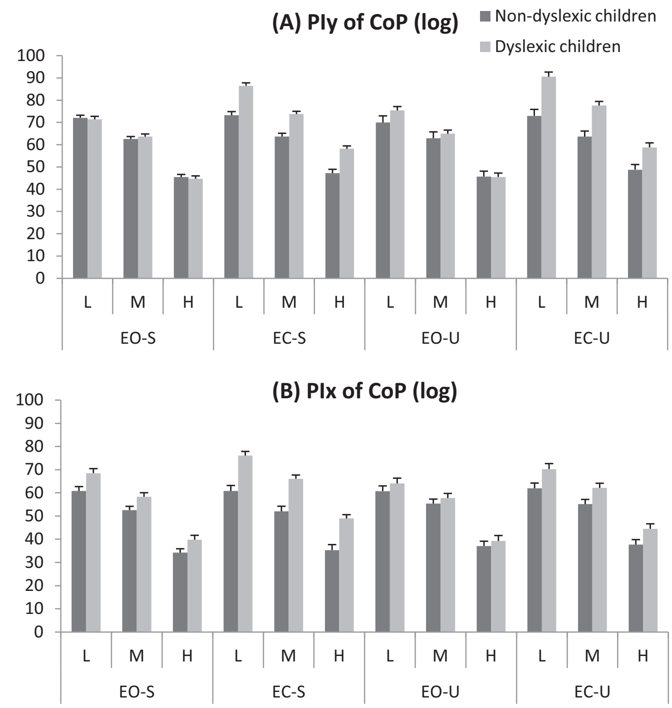

Fig. 5. Means and standard deviations of spectral power indices in antero-posterior (A) and in medio-lateral direction (B), for each frequency band (L, low, M, medium and H, high) in all conditions tested for dyslexic and non-dyslexic children.

3.2.2. Cancelling time in antero-posterior and medio-lateral direction

Fig. 6 shows the cancelling time in antero-posterior (CTy) and medio-lateral (CTx) direction in all four conditions tested for dyslexic and non-dyslexic children.

For cancelling time in antero-posterior direction, analysis of variance (ANOVA) shows a significant effect of frequency ($F_{(2,11)} = 76.55$, $p < 0.001$). The cancelling time in antero-posterior direction is significantly longer in medium frequency than in low and high frequencies (all $p < 0.001$). Moreover, the cancelling time in antero-posterior direction in high frequency is significantly shorter than in low frequency ($p < 0.001$). Analysis of variance (ANOVA) shows a significant interaction between group, condition and frequency ($F_{(6,34)} = 2.05$, $p < 0.05$). Indeed, in eyes open on unstable support condition (EO-U), dyslexic children have a cancelling time in antero-posterior direction, for each frequency (low, medium and high) significantly shorter than in non-dyslexic children (all $p < 0.04$).

For the cancelling time in medio-lateral direction (Fig. 6B), analysis of variance (ANOVA) shows a significant effect of group ($F_{(1,57)} = 4.16$, $p < 0.04$), that is, the cancelling time in medio-lateral

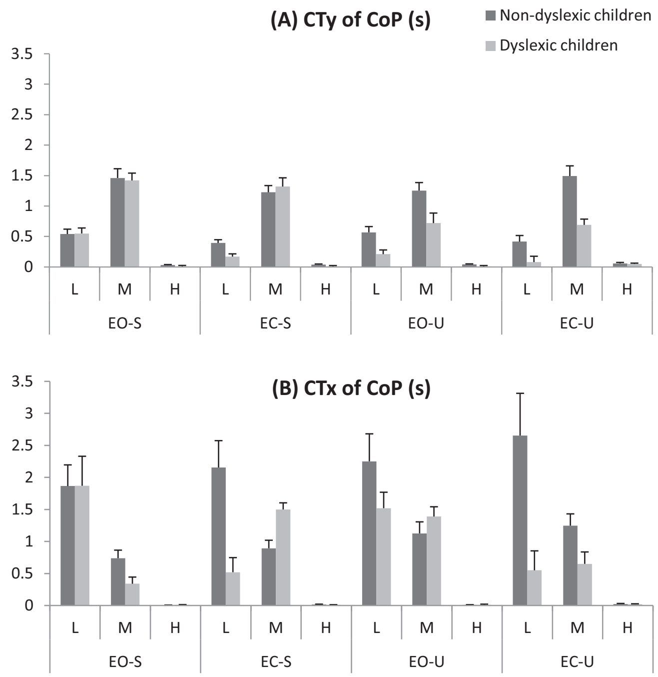

Fig. 6. Means and standard deviations of the cancelling time in antero-posterior (A) and in medio-lateral direction (B), for each frequency (L, low, M, medium and H, high) in all conditions tested for dyslexic and non-dyslexic children.

direction in dyslexic children is significantly shorter than in non-dyslexic children. Moreover, analysis of variance (ANOVA) shows a significant effect of frequency ($F_{(2,11)} = 39.49$, $p < 0.001$). The cancelling time in medio-lateral direction is significantly longer in low frequency than in medium frequency which is significantly longer than in high frequency (all $p < 0.001$). Analysis of variance (ANOVA) shows a significant interaction between group and frequency ($F_{(2,11)} = 3.62$, $p < 0.02$). The cancelling time in medio-lateral, for low frequency in dyslexic children is significantly shorter than this recorded in non-dyslexic children ($p < 0.001$).

4. Discussion

The main findings of this study are as follows: (i) Our temporal analyses have confirmed that postural control is poor in dyslexic children with respect to age-matched non-dyslexic children, as reported by spatial analysis. (ii) Postural control depending on the condition: for both groups of children stability is better with eyes open on a stable platform. (iii) Different postural strategies are used by dyslexic children with respect to non-dyslexic children. Each of these findings will be discussed below.

(i) Temporal analyses have confirmed that postural control is poor in dyslexic children with respect to age-matched non-dyslexic children, as reported by spatial analysis

This work enlarges previous studies exploring postural control in dyslexic children from our group and several other groups already cited in the introduction. Indeed, classical spatial analysis of posture describes a surface area and a mean velocity of CoP greater in dyslexic children with respect to non-dyslexic children.
The novelty here is the use of the temporal analysis of the center of pressure. To our knowledge, it is the first time that postural control in dyslexic children has been studied with such analysis allowing the recording of the spectral power indices and the cancelling time of body sway in both medio-lateral and antero-posterior directions. The spectral power indices are significantly larger in dyslexic children than in non-dyslexic children suggesting that dyslexics made larger body oscillations. Furthermore, the cancelling time in the medio-lateral direction for all three frequencies examined is significantly shorter in dyslexic children with respect to non-dyslexic children. It is worth recalling that the longer the cancelling time is, the better the postural control because it is the time required to use sensorial inputs to maintain efficiently postural control. A shorter cancelling time could reveal a low use of sensorial information and thus a poor postural control (Dumistrescu and Lacour, 2006; Bernard Demanze et al., 2009). In line with this idea, we can suggest that dyslexic children are using less sensorial inputs or in uncorrected way to control their body sway and these findings are in agreement with a poor automaticity capability in these children, as shown by Barela et al. (2011).

(ii) Both groups of children show postural control depends on the conditions

Classical analysis of both groups of children shows that the surface area and the mean velocity of CoP are smaller with eyes open on a stable platform than on an unstable platform. Similarly and independently of the group of children, the wavelet analysis shows that the spectral power indices are smaller on stable than on unstable platforms. Together these findings suggest that on a stable platform sensorial information (visual, vestibular and somesthesic) is available, leading to a more efficient postural control. Furthermore when eyes are open on stable platform both groups of children use visual inputs in line with the study by Shumway-Cook and Woollacott (1985), showing that children are more visual-dependant that adults. Another important point is that on unstable platforms, postural control is lacking because the somesthesic information is misleading, according to the study by Hirabayashi and Iwasaki (1995). Depending on the condition, compensatory strategies are used to maintain good postural control. Polastri and Barela (2013), comparing three groups of children young, middle and old (4.8 and 12 years old respectively) and one group of young adults, showed that four-year old children have already developed the adaptive capability to 'weight' visual information quickly in order to maintain their postural stability. However young children do not fully calibrate their adaptive response and do not carry over their previous experience from the sensorial environment to adapt to future changes. Such capabilities develop later.

(iii) Different postural strategies are used by dyslexic children with respect to non-dyslexic children

In order to identify the different postural strategies in dyslexic children, first we will discuss differences pointed out by wavelet analysis between the two groups of children. In subjects with eyes open and eyes closed on unstable support condition, this study shows that the spectral power indices, in both medio-lateral and antero-posterior directions, is significantly higher in dyslexic children in respect to non-dyslexic children for all frequencies namely for medium frequency. According to previous works (Naschner, 1979; Kohen-Raz et al., 1996; Paillard et al., 2002; Lacour et al., 2008; Bernard Demanze et al., 2009), we assumed that dyslexic children could use sensorial information less than non-dyslexic children to control their body sway. Moreover, the low spectral power indices in medium frequency reported in dyslexic children could suggest a less cerebellar integration (Paillard et al., 2002). In subjects with eyes open on unstable support condition, we observed that also the cancelling time, in the antero-posterior direction only, is significantly smaller in dyslexic children in respect to non-dyslexic children for all frequencies, namely for medium frequency. Based on previous evidence (Naschner, 1979; Kohen-Raz et al., 1996; Paillard et al., 2002; Lacour et al., 2008; Bernard Demanze et al., 2009), we assumed that dyslexic children could use sensorial information, particularly cerebellar inputs less than non-dyslexic children to control their body sway. Thus, we could advance the hypothesis that the poor postural stability reported in dyslexic children may be due to a deficit in the cerebellar function. Indeed, the cerebellum makes it possible to integrate several types of sensorial information to maintain postural control, and dyslexics are known to have cerebellar deficiencies (see Fawcett et al., 1996 for review). Neuropsychological studies also confirm such a hypothesis; for instance Rae et al. (1998), studying in dyslexic adult subjects, have found biomechanical lateral differences in the temporo-parietal lobes of the cerebellum that were not present in non-dyslexic adult subjects. An MRI study by Eckert et al. (2003) also found smaller right anterior lobes of the cerebellum in dyslexic children with respect to non-dyslexic children. On the other hand, we could assume that other cortical and central areas could be responsible of poor postural control in dyslexic children as discussed in previous studies (Ouchi et al., 1999; Tse et al., 2013). The poor vergence capabilities reported in dyslexic children suggests an immaturity of the cortical structures controlling vergence movements. Recent fMRI studies (Quinlan and Culham, 2007; Alkan et al., 2011) show activation of the parietal, occipital cortex and also of the frontal eye fields and midbrain while adult subjects performed convergence movements. Further morphological (CT or MRI) and/or functional (f-MRI) studies are required to explore eventual abnormalities in these structures in dyslexic population.

5. Conclusion

The results of this study suggest that the deficit in postural stability encountered in dyslexic children compared to non-dyslexic children could be due to a deficiency in sensory integration by the cerebellum as well as a lesser use of sensory information. Further research might explore whether postural training activities could develop cerebellar adaptation and increase information integration allowing dyslexic children to improve postural control in everyday life by learning to integrate and weight all sensory information.

Fundings

The authors are grateful to the Fondation Cotrel/Institut de France for their financial support.

Acknowledgements

The authors are grateful to parents and children for their kind participation. They also thank Ajrezo Layla, orthoptist and Damien Melithe optometrist, for visual examinations children and Ms Meredith Wiseman for revising the English version of the manuscript.

Conflict of interest: The authors have declared that no conflicting interests exist.

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Please cite this article in press as: Gouleme N et al. Spatial and temporal analysis of postural control in dyslexic children. Clin Neurophysiol (2014), http://dx.doi.org/10.1016/j.clinph.2014.10.016

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