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A B S T R A C T

We compared the effect of oculomotor tasks on postural sway in two groups of ADHD children with and without methylphenidate (MPH) treatment against a group of control age-matched children. Fourteen MPH-untreated ADHD children, fourteen MPH-treated ADHD children and a group of control children participated to the study. Eye movements were recorded using a video-oculography system and postural sway measured with a force platform simultaneously. Children performed fixation, pursuits, pro- and anti-saccades. We analyzed the number of saccades during fixation, the number of catch-up saccades during pursuits, the latency of pro- and anti-saccades; the occurrence of errors in the anti-saccade task and the surface and mean velocity of the center of pressure (CoP). During the postural task, the quality of fixation was significantly worse in both groups of ADHD children with respect to control children; in contrast, the number of catch-up saccades during pursuits, the latency of pro-/anti-saccades and the rate of errors in the anti-saccade task did not differ in the three groups of children. The surface of the CoP in MPH-treated children was similar to that of control children, while MPH-untreated children showed larger postural sway. When performing any saccades, the surface of the CoP improved with respect to fixation or pursuits tasks. This study provides evidence of poor postural control in ADHD children, probably due to cerebellar deficiencies. Our study is also the first to show an improvement on postural sway in ADHD children performing saccadic eye movements.

Keywords: Children Dual-task Posture Eye movements ADHD Methylphenidate

1. Introduction

Children with attention-deficit hyperactivity disorder (ADHD) are characterized by the symptoms of impulsiveness, hyperactivity and inattention. ADHD is a prevalent neurobehavioral disorder estimated to affect 5% of children for some of whom these symptoms could persist into adulthood (Barkley, 1997).

Children with ADHD have shown deficiencies in sensorimotor processing (Parush, Sohmer, Steinberg, & Kaitz, 1997; Parush, Sohmer, Steinberg, & Kaitz, 2007). Neuroimaging studies of ADHD patients have also reported abnormalities in the

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brain regions such as the prefrontal cortex, which are important for executive function (Amen, Paldi, & Thisted, 1993; Zametkin et al., 1990; Vaidya et al., 1998) as well as in the cerebellum and basal ganglia, areas involved in the sensorimotor control (Filipek et al., 1997; Diamond, 2000; Gustafsson, Thernlund, Ryding, Rosen, & Cederblad, 2000; Kim, Lee, Shin, Cho, & Lee, 2002). All these findings are in line with studies reporting poor motor performances in children with ADHD. Zang, Gu, Qian, & Wang (2002) and Wang, Wang, & Ren (2003) have examined sensory contributions to postural abilities in children with ADHD. Both studies have found that the sway velocity of the center of pressure (COP) was significantly higher in the ADHD children group than in the control group under various testing conditions (e.g., standing with the eyes closed, standing on a foam pad). They suggested that balance control is an important sensorimotor function that could be compromised in the ADHD children because it requires the capability to integrate inputs from various sensory systems (i.e., somatosensory, visual, vestibular) in order to maintain body equilibrium. Furthermore it should be noted that postural control is not a simple reflex task, but that it demands attentional resources (Woollacott & Shumway-Cook, 2002). Over the last decade, several studies have examined the postural control of children as they are asked to accomplish a secondary task requiring the focus of attentional resources. Olivier, Cuisinier, Vaugoyeau, Nougier, & Assaiante (2010) have suggested that two independent attentional mechanisms could exist, one for controlling posture and the other one responsible for the secondary cognitive task. These two mechanisms could interfere with each other depending on the difficulty of the dual task – cognitive and postural. Recent work from Shorer, Becker, Jacobi-Polishook, Oddsson, & Melzer (2012) has examined postural performance during simple and dual tasks (listening and memorizing children's songs) conditions in ADHD children. They found that ADHD children showed poor postural stability with respect to control children under both conditions (simple as well as dual-task), suggesting that postural control is affected by attention deficit disorders. Interestingly, postural sway was reduced in dual task compared to simple task condition in both ADHD and control children, suggesting improved control of balance during dual task. This result is in line with the hypothesis that a secondary task can shift the attentional focus away from postural control leading to a better automatic postural performance.

Several studies have also investigated eye movements in children with ADHD. Most of them have explored executive functions in these patients in order to test the hypothesis that the prefrontal areas, which are responsible for intentional motor performances, are affected in children with ADHD (for a review see Rommelse, Van der Stigchel, & Sergeant, 2008). For instance, more intrusive saccades are reported during fixation tasks (Gould, Bastain, Israel, Hommer, & Castellanos, 2001). The latency of pro-saccades has been also reported to be longer and more variable compared to controls (Munoz, Armstrong, Hampton, & Moore, 2003; Klein, Fischer, Fischer, & Hartnegg, 2002). On the other hand, other studies have failed to show any differences between children with ADHD and controls (Hanisch, Radach, Holtkamp, Herpertz-Dahlmann, & Konrad, 2006; Karatekin & Asarnow, 1998; O'Driscoll et al., 2005). Similarly, the results on anti-saccades performance in children with ADHD are inconsistent although a large number of studies report an elevated number of errors in the anti-saccade task for these patients (see Table 1 of the review from Rommelse et al., 2008). Finally, pursuit eye movements have also been investigated in children with ADHD and the findings are again in contrast with each other: Castellanos et al. (2000) do not report pursuit deficiencies in these patients while Gargouri-Berrechid et al. (2012) show lower pursuit gain for ADHD children. Taken together, all these reports however are in agreement with the idea of an increased variability of oculomotor performance in children with ADHD compared to the literature on controls (Kuntsi, McLoughlin, & Asherson, 2006; Leth-Steensen, Elbaz, & Douglas, 2000).

Methylphenidate (MPH) is frequently used as medication to treat ADHD patients (Wilens, Spencer, & Biederman, 2002) but little is known about its effect on postural and oculomotor performances. Leitner et al. (2007) have reported that children with ADHD under methylphenidate treatment show slight alteration/changes in walking with increased stride-to-stride variability that is not significantly different with respect to control children; Buderath et al. (2009) have also observed minor balance and stepping disorders in children with ADHD treated with methylphenidate at the time of testing, such impairment was similar to those reported in children with mild cerebellar dysfunction. Using the Movement Assessment Battery, Flapper, Houwen, & Schoemaker (2006) also found an improvement in the motor performances of children with ADHD after methylphenidate treatment. Jacobi-Polishook, Shorer, & Melzer (2009) have explored the effect of methylphenidate on postural stability in children with ADHD in single and dual-task conditions (while performing a memory attention demanding task such as memorizing children's songs while listening to music). These authors reported that postural performance improved significantly with methylphenidate only in the two dual-task conditions, suggesting that such a drug could enhance attention capabilities, leading to better postural stability when performing tasks that require attention.

The effect of methylphenidate was also investigated on eye movement performances but the results are quite discordant. For instance, Aman et al. (1998) reported no difference in performing anti-saccades before and after treatment. Mostofsky,

Table 1
Clinical characteristics of children examined.

Participants (years)	TNO (s of arc)	PPC (cm)	Phoria (pD)	Convergence (pD)	Divergence (pD)
ADHD off MPH (9.5 ± 0.5)	62 ± 8	3 ± 0.4	-0.7 ± 0.5	34 ± 2	$9.8 \pm 0.9^*$
ADHD on MPH (9.8 ± 0.6)	65 ± 9	4 ± 0.7	-1.8 ± 0.9	30 ± 3	$10 \pm 0.5^*$
Control (9.7 ± 0.8)	58 ± 8	3 ± 0.6	-1.8 ± 1	36 ± 4	18 ± 0.4

Clinical characteristic of ADHD children off and on methylphenidate and age-matched control children. Mean values of: binocular vision (stereoacuity test, TNO measured in seconds of arc); near point of convergence, NPC measured in cm; heterophoria at near distances measured in prism diopters; negative values indicate exophoria and positive values indicate esophoria; vergence fusional amplitudes (convergence and divergence) at near distances measured in prism diopters. Asterisks indicate that value is significantly different with respect to the group of control children ($p < 0.05$).

Lasker, Cutting, Denckla, & Zee (2001) compared the performance of pro- and anti-saccades in a group of children with ADHD with and without MPH with those of a group of age-matched control children. Both groups of children with ADHD made significantly more directional errors on the anti-saccade task than controls did, which is consistent with a deficit in response inhibition in the prefrontal areas. There were no significant differences in pro-saccade latency, although children with ADHD without MPH showed significantly larger variability in latency on the pro-saccades with respect to the control group. More recently, Seassau, Weiss, Carcangiu, and Duval (2013) have shown that children with ADHD being treated with MPH had normalized performances in reflexive saccadic tasks, while they were still impaired in voluntary attentional tasks (overlap). These findings suggest that MPH improves motor response although there so far there have been no observed improvements in response inhibition after MPH. Klein et al. (2002) have also reported an improvement after MPH in latency for both pro and anti-saccades and a reduction of the number of errors during the anti-saccades. Interestingly, these authors have observed that MPH increased the frequency of express saccades significantly, suggesting a weakening due to this drug in the fixation system. Recently, Allman, Ettinger, Joober, & O'Driscoll (2012) have examined the effects of MPH on oculomotor functions in normal participants. The latency of pro-saccades decreased significantly after MPH, the gain of smooth pursuits increased and the number of catch-up saccades during pursuit also decreased significantly. In contrast, the latency and the errors in the anti-saccade task were unaffected by MPH.

The goal of the present study was to explore the effect of eye movements on postural control in children with ADHD without and with MPH and to compare these data with those obtained from a group of age-matched control children. In order to gain a better insight into how eye movements influence postural control, we examined posture while different types of eye movements were performed: fixation, pro and anti-saccades and smooth linear pursuit movements. The novelty of the present study is that we recorded both eye movements and posture simultaneously.

Our driving hypothesis was that since attention is known to be involved in the execution of eye movements (Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Deubel & Schneider, 1996) as well as in postural stability (Woollacott & Shumway-Cook, 2002), interference between oculomotor and postural systems could be expected, and might be different in children with ADHD compared to control children. Secondly, we sought to examine further the effect of MPH on both oculomotor and postural performance.

2. Materials and methods

2.1. Participants

Twenty-eight children with ADHD (mean age 9.63 ± 0.7 years) were diagnosed at Robert Debré Pediatric Hospital in Paris by a pediatric neurologist and his team of psychologists. Diagnosis of ADHD was based on interviews with parents, teachers and children, clinical examination, and Conners' parent and teacher questionnaires (Conners, Sitarenios, Parker, & Epstein, 1998a,b). Children were not selected on the basis of subtype. All children underwent a complete neuro-developmental evaluation as part of the initial assessment at the clinic and were found not to suffer from any major neurological or motor disability other than ADHD. Children with ADHD were divided into two groups: one group of 14 children without medication and another group of 14children who were taking methylphenidate. For all children without medication at the moment of our test, methilphenidate was prescribed afterwards by clinicians.

A control group of 14 age-matched male children (mean age 9.75 ± 0.8 years) participated to the study. A pediatric neurologist examined control children to confirm their normal neurological status and to be sure that they did not suffer from any symptoms suggestive of ADHD, or other neurological or cognitive disability.

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.

2.2. Ophthalmologic and orthoptic evaluation

All children had normal values for ophthalmologic and orthoptic examination (Table 1 reports the clinical data obtained). The corrected visual acuity was normal (≥20/20) for all children. All children had normal binocular vision evaluated with the TNO random dot test. The near point of convergence (NPC) was normal for all children. Heterophoria (i.e. the latent deviation of one covered eye when the other is not covered) measured by using the cover–uncover test at near distance (30 cm) was normal for all children. Fusional amplitudes of convergence and divergence were measured at near distance (30 cm) by using a base-in and a base-out prism bar: children with ADHD (on and off MPH) showed poor divergence capabilities with respect to control children. ANOVA showed a significant group effect ($F_{(2,39)} = 5.95$, $p < 0.006$). LSD test showed that divergence values of children with ADHD (on and off MPH) were significantly smaller to the value measured in the control group of children (both $p < 0.0001$).

2.3. Visual tasks

Four visual tasks were designed and performed in separate sessions: fixation, pro and anti-saccades and pursuits. The stimuli were presented on a flat PC screen of 22 in., its resolution was 1920 × 1080 and the refresh rate was 60 Hz. Each task was performed during 25.6 s.

2.3.1. Fixation

Participants had to fixate a white-filled circle subtending a visual angle of 0.5° appearing in the center of the screen and switched on during the postural measurement. Note that even if this visual task is quite a difficult task requiring precise, active stabilization of the eyes, it is usually used as control task for postural measurement.

2.3.2. Pursuits

The target was moving on the PC's screen with a linear speed of 15°/s. The child was invited to follow the target with eyes without moving his/her head.

2.3.3. Pro-saccades

Horizontal, visually guided saccades were elicited using a gap paradigm. The stimulus was a red-filled circle subtending a visual angle of 0.5°. The trial consisted of a target positioned at the center of the screen for a variable delay comprised between 2000 and 3500 ms. After this fixation period, the central target was turned off and a target appeared 200 ms later (gap period) for 1000 ms to the right or to the left side of the screen. The central fixation target then reappeared, signaling the beginning of the next trial.

2.3.4. Anti-saccades

The trial consisted of a target positioned at the center of the screen for a variable delay comprised between 2000 and 3500 ms, followed by its disappearance during a gap interval of 200 ms. Then, a lateral target (green filled circle) appeared randomly to the left or to the right of the center, and stayed on for 1000 ms. The central fixation target then reappeared, signaling the beginning of the next trial. Children were instructed to look at the central fixation point, then to trigger a saccade as soon as possible in the opposite direction and symmetrically to the lateral target. Thus, when the target appeared on the right, the child had to look to the left, at a distance equivalent to the central point-target distance. When the target returned to the center, the child was instructed to visually follow it back to the center. An initial training block of trials was given to ensure that the instructions were well understood.

While performing the visual tasks, the child was standing on a platform, eye movements were recorded with the head-mounted eye-tracker and posture was recorded simultaneously.

2.4. Postural recording

To measure postural stability, we used a platform (principle of strain gauge) consisting of two dynamometric clogs (Standards by Association Française de Posturologie, produced by TechnoConcept, Céreste, France). The excursions of the center of pressure (CoP) were measured for 25.6 s; the equipment contained an analog–digital converter of 16 bits. The sampling frequency of the CoP was 40 Hz.

Postural measurements were performed in Standard Romberg condition: the heels were placed 4 cm apart and feet positioned symmetrically with respect to the participant's sagittal axis at a 30° angle.

For each visual task two postural recordings were done successively. The order of the visual tasks varied randomly across children. The experimental sessions took place in a dark room. Participants were placed 60 cm away from the screen, where visual tasks were presented at eye level. Participants were asked to stand without moving their body and with their arms along their body.

2.5. Eye movement recording

During the postural recording, eye movements were recorded binocularly by a non-invasive system using high definition camera and mirror; horizontal and vertical eye position were recorded independently and simultaneously for each eye with the Mobile EyeBrain Tracker (Mobile EBT®, e(ye)BRAIN, www.eye-brain.com), an eye-tracking device CE-approved for medical applications. Recording frequency for both eyes was set up to 300 Hz.

Calibration was done at the beginning of eye movement recordings when the child was already on the platform. The calibration consisted of a succession of red points (diameter 0.5°) presented on the screen following a grid of 13 points. The calibration was calculated for a period of fixation of 250 ms for each point (see Lions, Bui-Quoc, Seassau, & Bucci, 2013, for details). The task started immediately after the calibration.

2.6. Data processing

To quantify the effect of visual tasks on the postural performance, two parameters of the platform recording were analyzed: the surface area and the mean speed of the center of pressure (CoP). The surface of CoP corresponds to an ellipse with 90% of CoP excursions. The mean speed represents a good index of the amount of neuromuscular activity required to regulate postural control (Maki, Holliday, & Fernie, 1990; Geurts, Nienhuis, & Mulder, 1993).

Eye movements were analyzed using the better signal of both eyes. During the fixation task, the number of intrusive saccades with amplitude $\geq 2°$ was counted. It is well known that microsaccades are normally smaller than such amplitudes (Krekelberg, 2011). For pursuit movements, the number of catch-up saccades was measured (saccades made in the pursuit direction, with amplitude ≥ 2°). For each saccade recorded during the pro and anti-saccades tasks, we examined the latency value in milliseconds (i.e. time needed to prepare and trigger the saccades). Furthermore, in the anti-saccade task the mean error rate was also examined (i.e. the number of saccades made in the target direction).

The MeyeAnalysis© software (provided with the eye tracker, see www.eye-brain.com) was used to determine automatically the onset and the end of each saccade by using a 'built-in saccade detection algorithm'. All detected saccades are verified by the investigator and corrected or discarded as necessary (see Bucci & Seassau, 2012).

2.7. Statistical analysis

An ANOVA was performed with groups of children as inter-subject factor and tasks as within subject factor. Post hoc comparisons were made with the Fischer's least significant differences (LSD) test used to explore further and compare the mean of one oculomotor task or postural position with the mean of another. The effect of a factor was considered as significant when the *p*-value was below 0.05.

3. Results

3.1. Eye movements

Fig. 1A shows the mean number of intrusive saccades during fixation for each group of children. The ANOVA showed a significant effect of group ($F_{(2,39)} = 4.59$, $p < 0.01$): the number of intrusive saccades during fixation in children with ADHD

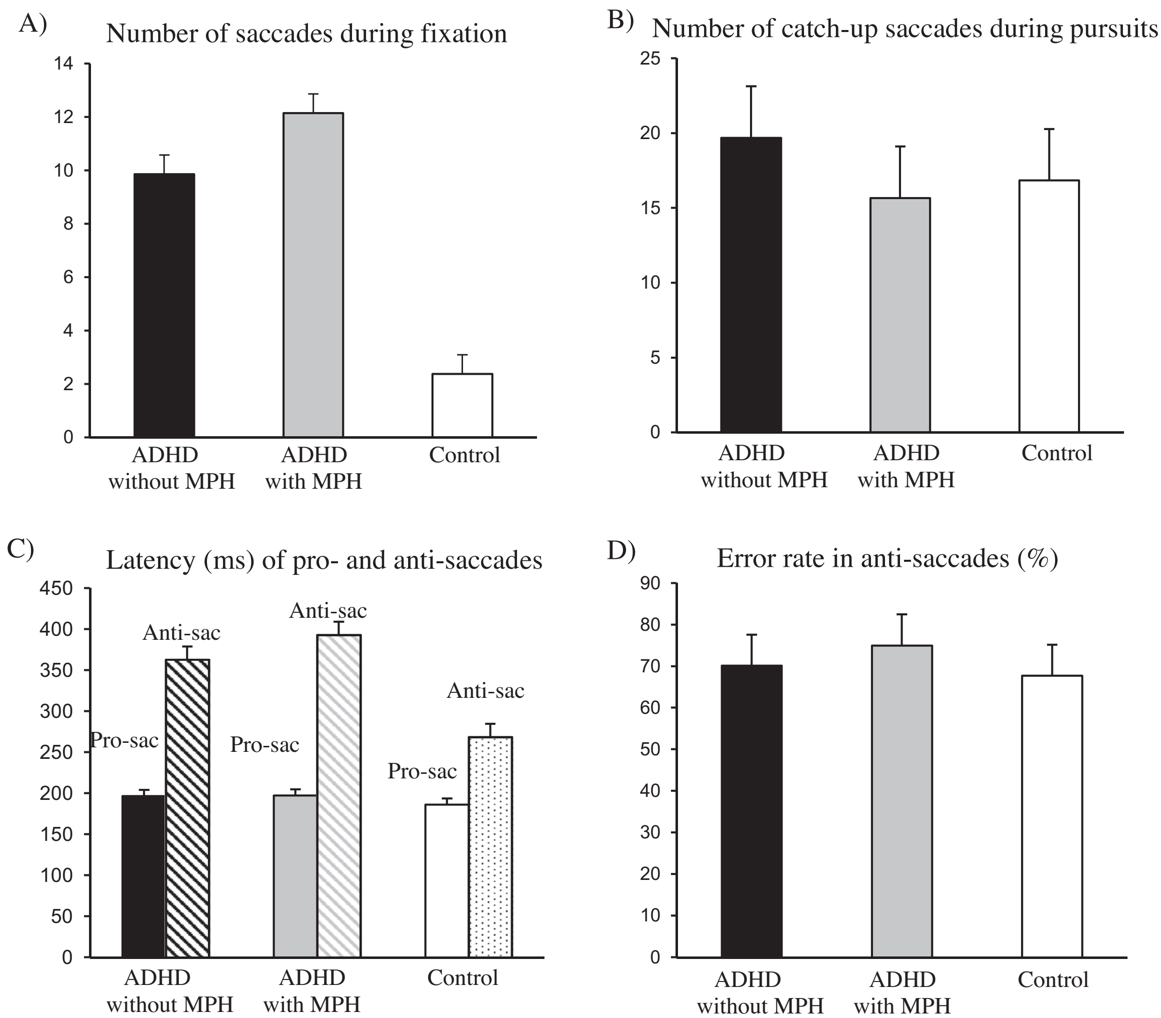

Fig. 1. Eye movements recorded during postural task for the three groups of children examined (ADHD children off and on methylphenidate and age-matched control children). (A) Mean values of number of saccades during fixation. (B) Mean values of number of catch-up saccades during pursuits. (C) Mean values of latency (in ms) of pro- and anti-saccades. (D) Mean error rate in anti-saccades (in percentage). Vertical bars indicate the standard error.

was significantly larger than those reported in the control group of children (LSD test, $p < 0.03$ and $p < 0.006$ for children with ADHD off and on MPH, respectively).

Fig. 1B shows the mean number of catch up saccades recorded during pursuits. ANOVA did not show any difference between the three groups of children tested ($F_{(2,39)} < 1$).

Fig. 1C shows the mean latency of pro and anti-saccades for the three groups of children. The ANOVA did not show a significant difference between the three groups ($F_{(2,39)} = 1.52$, $p = 0.23$), but only a significant effect of the task. Latency values of anti-saccades were significantly longer to that of pro-saccades ($F_{(2,39)} = 26.00$, $p < 0.00001$).

Finally the error rate observed during the anti-saccade task is shown in Fig. 1D. The mean error rate was not different in the three different groups of children and the ANOVA failed to show significant difference ($F_{(2,39)} < 1$).

3.2. Postural control

Fig. 2A shows the mean surface of the CoP for the three groups of children during fixation, pursuits, pro- and anti-saccades tasks. The ANOVA showed a significant group effect ($F_{(2,39)} = 8.55$, $p < 0.0008$). Post hoc comparisons showed that the mean value of the surface of the CoP for children with ADHD off MPH was significantly larger than the mean value of the surface of the CoP of children with ADHD on MPH ($p < 0.02$) and of control children ($p < 0.001$).

The ANOVA showed a significant effect of the visual task ($F_{(3,117)} = 6.76$, $p < 0.0003$). Post hoc comparisons showed that the mean value of the surface of the CoP was significantly smaller during pro-saccades with respect to fixation ($p < 0.0008$) and pursuits ($p < 0.0009$); similarly, the mean value of the surface of the CoP was significantly smaller in the anti-saccades than in fixation and pursuits ($p < 0.003$ and $p < 0.004$, respectively). The ANOVA failed to show a significant interaction between groups and tasks ($F_{(3,117)} < 1$).

Fig. 2B shows the mean value of the mean speed of the CoP for the three groups of children during fixation, pursuits, pro- and anti-saccades tasks. The ANOVA showed a significant group effect ($F_{(2,39)} = 8.22$, $p < 0.001$). Post hoc comparisons showed that the mean value of the mean speed of the CoP for control group of children was significantly smaller to that of children with ADHD off and on MPH ($p < 0.0003$ and $p < 0.006$, respectively).

The ANOVA showed a significant effect of the visual task ($F_{(3,117)} = 4.24$, $p < 0.007$); post hoc comparisons showed that the mean value of the mean speed of the CoP during performing pro-saccades was significantly smaller to that of the other visual

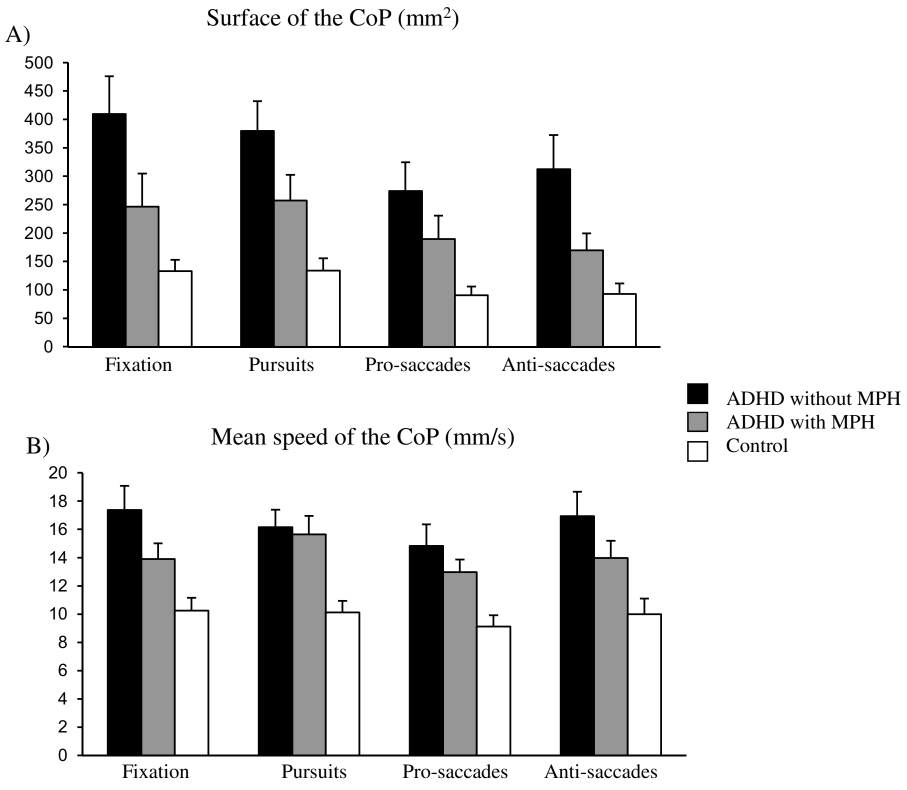

Fig. 2. Postural parameters recorded during fixation, pursuits, pro- and anti-saccades for the three groups of children examined (ADHD children off and on methylphenidate and age-matched control children). (A) Mean values of the surface of the CoP (in mm^2) during fixation, pursuits, pro- and anti-saccades. Vertical bars indicate the standard error. Asterisks indicate that the value is significantly different ($p < 0.05$). (B) Mean values of the mean speed of the CoP (in mm/s) during fixation, pursuits, pro- and anti-saccades. Vertical bars indicate the standard error. Asterisks indicate that the value is significantly different ($p < 0.03$).

task ($p < 0.007$, $p < 0.002$ and $p < 0.006$, respectively for fixation, pursuits and anti-saccades). The ANOVA failed to show a significant interaction between groups and tasks ($F_{(3,117)} < 1$).

4. Discussion

The main findings of this study are as follows: (i) During the postural task, the quality of fixation is significantly worse in children with ADHD off and on MPH with respect to control children; in contrast, the number of catch-up saccades during pursuits, the latency of pro- and anti-saccades and the rate of errors in anti-saccade tasks is not different in the three groups of children tested; (ii) The surface area of the CoP in children with ADHD on MPH is similar to control children while children with ADHD off MPH show larger postural sway; (iii) When performing saccades (pro- or anti-tasks), the surface area of the CoP improves, compared with fixation or pursuits tasks. These findings are discussed individually below.

4.1. Quality of eye movement performance during postural task

In the present study we show that during a dual task, the performance of pursuits and saccades (pro- as well as anti-saccades) is similar in children with ADHD (off and on MPH) and control children. This result is in agreement with previous studies examining saccade performance in children with ADHD in a simple task (Hanisch et al., 2006; Karatekin & Asarnow, 1998; O'Driscoll et al., 2005); indeed these authors have shown that the latency of pro- and anti-saccades is similar in ADHD and control children. With respect to pursuit performance in our test, we did not find any difference between the three groups of children. This result is in line with a study by Castellanos et al. (2000) who did not observe any differences in pursuit eye movements in ADHD and control children. It should also be noted that in the present study MPH did not improve saccade and pursuit performances according to Aman et al. (1998).

The only difference we observed between ADHD and control children was in the quality of fixation during a dual task; children with ADHD (off and on MPH) made significantly more saccades during the fixation task than control group children. The quality of fixation is rarely reported in studies of children, but a recent study from our group (Ajrezo, Wiener-Vacher, & Bucci, 2013) explored the quality of fixation during dual postural task in a large population of children and showed that children of 12 years made few saccades during fixation. Interestingly, our control group did the same amount of saccades during the same fixation task. In contrast, the two groups of children with ADHD showed more instability in fixation. This finding could be in relation to their visual attentional deficits and their difficulty to inhibit unwanted saccades during a fixation task. However, such immaturity and/or deficiency of the fixation system did not lead to an abnormal occurrence of express saccades in these children. It is worth recalling that express saccades have been considered to reflect the release of fixation or visual attention (Breitmeyer, 1993; Fischer & Weber, 1993). However, the occurrence of express saccades during gap paradigm recorded in the dual task is similar in children with ADHD ($22 \pm 5\%$ and $19 \pm 4\%$, respectively for children off and on MPH) and in controls ($20 \pm 3\%$). This finding contrasts the reports from Klein, Raschke, & Brandenbusch (2003) showing that during a single oculomotor task (gap paradigm), children with ADHD did fewer express saccades than control children. Other studies examining fixation capabilities in larger population of children with ADHD will be interesting to gain further insight into the fixation system.

Finally, it is worth pointing out that all three groups of children made a high number of errors while performing anti-saccades during postural task. Indeed, for 12-year-old control children, it is known that the error rate in the anti-saccade task is about 23% only (see Bucci & Seassau, 2012). Children tested in the present study (ADHD off and on MPH) as well as control children showed about 70% of errors for the anti-saccade task performed during postural measure. This could be explained the similar effect of pro- and anti-saccades on postural sway (discussed later).

4.2. Poor postural stability in children with ADHD

The present study shows that postural stability in children with ADHD is worse than in control children. This finding is in line with the data reported by Shorer et al. (2012) showing that postural stability in 9-year-old children with ADHD was poor with respect to control children of a similar age. This finding is in line with the hypothesis of an increase in the threshold of peripheral sensory captors responsible for controlling postural stability; on the other hand, the instability found in children with ADHD could be due their difficulty to pay attention to the motor task for minimizing sway due to their cerebral dysfunction. Indeed, imaging studies (Mulas, Mattos, de la Osa-Langreo, & Gandía, 2007) reported atrophy in cerebellum regions associated with gait and balance in children with ADHD.

Interestingly, Shorer et al. (2012) compared postural sway during a simple task (fixation of a cross) as well as during a dual task (auditory-memory-demanding task) and they found that both groups of children (ADHD and control) decreased postural sway in the dual task compared to simple task. The result of the improvement in the control of balance during dual-task is in line with the hypothesis that a secondary task can shift the attentional focus away from postural control leading to a better automatic postural performance. In the next section we will focus on the different effects of different types of eye movements on balance control.

4.3. Eye movements affect postural sway

The effect of oculomotor tasks in postural control is still controversial and few studies have recorded eye movements and postural sway in children simultaneously. Our results show that performing saccades improves postural stability with respect to a simple fixation task. This finding is in line with the report of Ajrezo et al. (2013) showing in a large sample of children a decrease in postural sway as children performed saccades with respect to fixation task.

The finding showing large instability when performing pursuit eye movements is new; indeed one study only (Glasauer, Schneider, Jahn, Strupp, & Brandt, 2005) has reported an increase of postural instability in Tandem Romberg position when adult participants were making pursuit eye movements. Furthermore we have to point out that pro- and anti-saccades affected the surface areas of the CoP in a similar way but not the mean speed of the CoP, for which performing anti-saccades tasks leads to a significant increase of these parameters. Recall that the mean speed of the CoP, according to Maki et al. (1990) and Geurts et al. (1993), is believed to reflect the muscular energy used by the body for self-stabilization. Most likely ADHD and control children use the speed strategy to try to perform both tasks (posture and anti-saccade) in a correct way.

Taken together our results are in line with the U-shaped non-linear interaction model described by Huxhold, Li, Schmiedek, & Lindenberger (2006), which try to explain the effect of a secondary task during postural task. The secondary task could either increase or decrease postural stability depending on the type of it, and on the attentional cost of such a task. For instance, fixation and pursuit eye movements are quite difficult attention-demanding tasks leading to degradation of the postural sway. In contrast, an easy task, such as making saccades, shifting the attentional focus away from postural control, leads to a better automatic postural performance.

5. Conclusion

In conclusion, this study provides evidence about poor postural control in ADHD children, probably due to their cerebellar deficiencies. Furthermore, we have shown for the first time an improvement on postural sway in ADHD children when they perform saccadic eye movements. This study provides a context for clinicians and trainers to focus on saccade tasks for balance skill training aiming to improve performance in ADHD children.

Finally, the beneficial effect of the MPH treatment is perceptible in the quality of fixation, which becomes similar to that reported in control children. Further studies exploring oculomotor and postural performances on the same children before and after MPH treatment will be necessary to clarify the improvement of attentional performance in ADHD children on MPH.

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Competing interests

Magali Seassau declares work for the e(ye)BRAIN company. The co-authors have no competing interests to declare.

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