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Interactions between eye movements and posture in children with neurodevelopmental disorders

Running head: Poor oculomotor and postural control in children with neurodevelopmental disorders

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This research article brings evidence that:

- Eye movement's parameters were differently affected by postural conditions
- The quality of fixation was weak in children with neurodevelopmental disorders with respect to typically developmental children, specifically in conditions where subjects were standing up on the platform

- Postural stability was poor in children with neurodevelopmental disorders with respect to typically developing children

Abstract

In everyday life, our activities frequently involve the simultaneous performance of two or more tasks. Sharing attention between two concurrent tasks may result in a decrease in performance specifically among children with neurodevelopmental disorders. The objective of the study was to determine whether the influence of postural conditions (sitting condition, single task; standing condition, dual task) on eye movement performances on three visual tasks with high attentional load (visually-guided saccade task, memory-guided saccade task and fixation task) was different in children with neurodevelopmental disorders (attention deficit and hyperactive disorder, dyslexia, and high functioning autism spectrum disorder) when compared to typically developing children. One hundred and four children (26 per group, sex-age- and IQ-matched groups) were evaluated. We found that for the fixation task only, the three groups of children with neurodevelopmental disorders had poorer eye movements performances in the standing condition compared to the sitting condition while no such difference was found for typically developing children. We suggest that children with neurodevelopmental disorders have fewer attentional resources available for performing correctly oculomotor tasks with high attentional load leading to impairment of these tasks for maintaining a good level of postural stability.

Abbreviations

ADHD = attention deficit hyperactivity disorder;

ASD = autism spectrum disorder;

TD = typically developing children;

IQ = intelligence quotient;

CoP = center of pressure;

VGS = visually-guided saccades;

MGS = memory-guided saccades;

Keywords: Dyslexia, Autistic Spectrum Disorder, ADHD, Cerebellum, Postural Control, Eye Movements

Introduction

Postural control requires sensorimotor integration of vestibular, visual and proprioceptive information (Brandt, 2003). However attention plays a major role in postural stability and its importance depends on several factors including the type of task or of the sensory information available, but also the age of subjects (Shumway-Cook and Woollacott, 2000; Woollacott and Shumway-Cook, 2002). To explore further the involvement of attention on postural control, several studies have been conducted to examine the effect of a secondary task on postural stability. Huxhold et al. (2006) observed that the secondary task could either increase or decrease the postural stability following a U-shaped non-linear interaction model. The effect on the postural stability depended on the type of the task, specifically on its attentional cost.

For example, our group was pioneer in recording both eye movements and postural performance at the same time in children. We thus reported on a large number of healthy children that performing eye movements during a postural task is a quite difficult attention-demanding duty leading to a change of the postural sway depending itself on the type of executed eye movements. For instance, visually-guided saccades (saccades to visual target) (Ajrezo et al. 2013) and anti-saccades (saccades in the opposite direction of the visual target) (Ajrezo et al. 2015) decreased the postural sway.

An important question was how eye movements can interfere with postural stability in children with neurodevelopmental disorders since most of them displayed both poor eye movement performance as well as poor postural control. Indeed, several studies in children with attention deficit and hyperactive disorders (ADHD) reported impairments in their oculomotor capabilities suggesting a general deficit in visual fixation (for review, see Rommelse et al. 2008). Similarly, our group (Bucci et al. 2017a) replicated these findings and suggested further that children with ADHD could have a deficit in the inhibitory capabilities. Atypical saccades and ocular tracking as well as deficit in vergence movements were also reported in children with dyslexia (Stein et al. 1988, Eden et al. 1994, Bucci et al. 2012; Tiadi et al. 2016). Children with autism spectrum disorder (ASD), even if the majority of eye movement studies have focused on scan patterns of social scenes and facial expressions (Franchini et al. 2017, Moriuchi et al. 2017), displayed difficulties with attentional engagement in oculomotor tasks (Luna et al. 2007).

We recently recorded both eye movements and postural sway, and examined the quality of eye fixation, saccades (toward visual stimuli and on the opposite direction of the visual stimuli) and smooth pursuit movements in children with ADHD and in children with dyslexia (Bucci et al. 2014a, Bucci et al. 2014b). When exploring the postural stability, the quality of fixation was impaired during a dual task both in children with ADHD and in children with dyslexia. These patients had a deficit in allocating visual attention and a difficulty to inhibit unwanted saccades. In parallel, saccades (towards and away to the visual target) affected postural stability leading to a decrease of postural sway. We believe that making saccades is an easy task shifting the attentional focus away from postural control, leading to a better automatic postural performance. In a previous study (Bucci et al. 2013) we also explored the effect of eye movements on posture in a small sample of children with autism with no verbal communication. We observed that saccades had a tendency to increase the surface of the

center of pressure in these children. We hypothesized that postural difficulties in children with neurodevelopmental disorders could be, most likely, due to poor use of sensory inputs to compensate natural body perturbation due to cerebellar impairment deficiencies in cerebro-cortical network (Bucci et al. 2017b).

Taken together, all these studies suggest that visual attention has a major role to control postural stability. They also advocate that the use of distinct types of eye movements could be useful to explore the relationship between posture and visual attention in children with neurodevelopmental disorders. Indeed, it is well known that attentional mechanisms are involved in eye movements' execution (Rizzolatti et al. 1997), and also that several cortical and central areas are involved in both postural and eye movements control (Ouchi et al. 1999).

In this study, we hypothesized that eye movements performance, specifically oculomotor tasks in which attention is highly demanded, will be deficient in children with neurodevelopmental disorders and that the impairment will be correlated with the difficulty of the postural condition (*i.e.* when children are standing up on platform with respect to when they are comfortably sitting). We also explored if the postural stability could be influenced by oculomotor tasks in line with the U-shaped non-linear interaction model described by Huxhold et al. (2006). Huxhold et al. (2006) suggested an improvement of the postural sway under conditions in which participants were focusing their attention on a secondary task leading to an automatization of the postural control, while when the attentional demand for the secondary task increased, a degradation of the postural sway could be observed. Our goal in the present study was to test whether different types of oculomotor task could have a different effect on postural sway in children with neurodevelopmental disorders.

Materials and Methods

Subjects

Four different groups of twenty-six children sex-, IQ-and age-matched participated to the study (Table 1): group 1 to 4 included respectively children with ADHD, children with dyslexia, children with high functioning (ASD) and typically developing children (TD). All subjects from groups 1, 2 and 3 were enrolled in the study at the Child and Adolescent Psychiatry Department, Robert Debré Hospital (Paris, France) in which the Centre for Language and Learning Disabilities, the Expert Centre for High Functioning ASD and the Expert Center for Attention Deficit Hyperactivity Disorder are included. All children had a neurological exam in the normal range and were naïve of psychotropic treatment at inclusion. All children included in the study had a mean intelligence quotient (IQ) in the normal range (between 85 and 115). The IQ was evaluated using the Wechsler Intelligence Scale for Children (fourth edition) for groups 1 to 3. The IQ in typically developing children was estimated using two subtests, one assessing the verbal abilities (similarities) and one the non-verbal abilities (matrix reasoning). Typically developing children were sons and daughters of hospital employees. The clinical characteristics of all four groups of children were summarized in Table 1.

The diagnosis of ADHD was done according to Diagnostic and Statistical Manual of Mental Disorders, 5th ed. (DSM-5) criteria (APA, 2013) and was carried out using a semi-structured interview, the Kiddie-SADS (Kiddie Schedule for Affective Disorders and Schizophrenia, Goldman et al. 1998). ADHD symptom severity was assessed using the ADHD Rating Scale-parental report (ADHD-RS). This scale is based on a large collection of normative data and has demonstrated reliability and discriminant validity in children and adolescents (Du Paul et al. 1998; Collett et al. 2003). Dyslexic children were recruited from the Centre for Language and Learning Disabilities, to which they had been referred for an extensive evaluation of

their dyslexia, including an examination of their phonological capabilities. For each child, we measured the time required to read a text, the comprehension of the text and the ability to read words and pseudo-words using the L2MA battery (oral Language, written Language, Memory, Attention, Chevrie-Muller et al. 1997). Subjects with more than two standard deviations from the normal mean were included in the study. Children with ASD were included at the Expert Centre for High Functioning ASD. The diagnosis was done according to DSM-5 criteria (APA, 2013) and based upon the ADI-R (Autism Diagnostic Interview-Revised, by Lord et al. 1994), and the ADOS (Autism Diagnostic Observation Schedule, by Lord et al. 2000). Note that for TD children the values of these two tests was between 0-1. Subjects from group 1 with a comorbid diagnosis of dyslexia and ASD were not included. In the same line, subjects from group 2 had to be without ADHD and ASD and those from group 3 had to be without ADHD and dyslexia. In all the 3 groups, subjects with a developmental coordination disorder evaluated by the Movement Assessment Battery for Children (M-ABC, by Henderson and Sugden, 1992) were also not included in the study. The investigation adhered to the principles of the Declaration of Helsinki and was approved by our Institutional Human Experimentation Committee (Comité de Protection des Personnes CPP, Ile de France V). Written informed consent was obtained from children and their parents after the nature of the procedure was explained.

Visual tasks

Three visual tasks were designed and performed in separate sessions: horizontal visually-guided saccades, horizontal memory-guided saccades and fixation (see Figure 1). They were also recorded simultaneously in two different postural conditions: (i) while children were sitting comfortably on a chair and (ii) while children were standing up on a platform. The

central target and the stimulus were a white-filled square subtending a visual angle of 0.5° , presented on a 22 inch flat screen.

Visually-guided saccades (VGS): visually-guided saccades were elicited using a simultaneous paradigm. Children had to fixate a central target for a period randomly ranging between 2000 and 3500 ms, then it disappeared and a target at 20° on the left or on the right side of the screen was switched on for 1000 ms. The central target then reappeared, signaling the beginning of the next trial.

Memory-guided saccades (MGS): in the memory-guided saccade paradigm the children had to look at a central target for a period randomly ranging between 2000 and 3500 ms, and a target appeared for 300 ms at 20° on the right or on the left side of the screen. The central target extinction occurred 1000 ms after peripheral target presentation. The children were instructed to look at the center of the screen while the peripheral target was switched on. Children had to remember the location of this peripheral target, to wait for the extinction of the central target, and finally, only after the switched off of the central target, to make a saccade directed toward the remembered target location.

28 visually-guided saccades and 28 memory-guided saccades (VGS and MGS, respectively) had been stimulated for each postural condition.

Fixation: The children had to fixate the target appearing on the center of the screen and hold on during 30 sec. Fixation task was run two times.

Eye movements recoding

Eye movements were recorded using the Mobil EBT®, a CE-marked medical eye-tracking device (www.suricog.fr). It benefits from cameras that capture the movements of each eye independently. Recording frequency is set up to 300 Hz. The precision of this system is 0.25° . There is no obstruction of the visual field with this recording system. The experimental

sessions for both postural conditions took place in a dark room to avoid that the children could fixate other stimuli and their head was stabilized by a headrest supporting both the forehead and chin. The children were placed 60 cm away from the screen, where visual tasks were presented at eye level and viewing was binocular. For each visual task, the recording of eye movements was done without any break between the different visual tasks. The order of the visual tasks and of postural conditions varied randomly across children.

Calibration was done at the beginning of eye movements recording for each postural condition (sat down and standing up on the platform). The calibration consisted of a succession of red points (diameter 0.5°) presented randomly on the screen following a grid of 13 points (3 points horizontally upward, eye level and downward of the screen at -20° , 0° and $+20^\circ$) and other 2 points at 5° on the right and on the left at 7° upward and downward of the screen). The calibration was calculated for a period of fixation of 250 ms for each point (see Lions et al. 2013, for details). The task started immediately after the calibration.

Postural recording

Postural performance was evaluated using the Multitest Equilibre, also called Balance Quest, from Framiral® with a static platform (www.framiral.fr). The displacement of the Center of pressure (CoP) was sampled at 40 Hz. The children were placed on the Framiral® platform in a dark room and they were positioned with the feet aligned in parallel on the footprints, and the arms hanging along the body. The duration of each postural recording was 30 seconds, with a 15-second rest period between conditions to reduce the possible effects of tiredness. During the visual tasks, the children were asked to stand up but without moving the head and the body while holding the arms along it.

Data processing

To quantify performance of the visual tasks during the two different postural conditions (sitting and standing up on the platform), eye movement from the dominant eye (evaluated by the hole-in-the-card test) of each child were analyzed. For each saccade recorded during both visually-guided and memory-guided saccade paradigms, we examined the latency of the saccades *i.e.* the time needed to prepare and trigger the saccades. For memory-guided saccades, the number of erroneous saccades made before the extinction of the fixation target (during the memory delay period) was also analyzed. During the fixation task, the number of saccades with amplitude $\geq 2^\circ$ was counted, since microsaccades are normally smaller than such amplitude (see Tiadi et al. 2016). The MeyeAnalysis software (provided with the eye tracker) was used to determine automatically the onset and the end of each saccade by using a 'built-in saccade detection algorithm.' All detected saccades were double checked by the investigator; in other word the MeyeAnalyse software allows to show us on the screen the eye movements and the stimulus elicited (Bucci et al. 2012).

Saccades discarded (due to blinks or to latency longer than 1000 ms) were 1%, 4%, 3% and 3% respectively for TD, ADHD, ASD and dyslexic children group in the sitting condition while were 2%, 4%, 4% and 3% respectively for the TD, ADHD, ASD and dyslexic children group in the standing up on platform condition.

Furthermore, to quantify the effect of visual tasks on standing up on platform we measured the surface area and the mean velocity of the center of pressure (CoP). The surface of the CoP corresponds to an ellipse with 90% of CoP excursions (Chiari et al. 2002) and the mean velocity represents a good index of the amount of neuromuscular activity required to regulate postural control (Maki et al. 1990).

Statistical analysis

Statistical analysis using the GLM (General Linear Models) in STATISTICA® was

performed with the different groups of children as between-subject factors and the individual means of eye movements and postural parameters as within-subject factors. In more details three ANOVA analyses were conducted: for comparison of latencies in VGS vs MGS (2 tasks x 4 groups x 2 postural conditions); for errors in MSG (4 groups x 2 postural conditions); and for fixation (4 groups x 2 postural conditions).

Post-hoc comparisons were made with the Fischer's least significant difference (LSD) test. The effect of a factor was considered significant when the p-value was below 0.05.

Results

We measured the Eye movement performance in the two postural conditions (sitting and standing up on the platform).

Latency of saccades

Figure 2 shows the latency of visually-guided and memory-guided saccades for each groups of children tested in the two different postural conditions (sitting and standing up on the platform). The results of ANOVA showed that memory-guided saccades had longer latency with respect to visually-guided saccades ($F_{(1,100)}=193.42$, $p<.001$, partial $\eta^2 = 0.36$). ANOVA failed to report any significant effect of groups ($F_{(1,100)}=0.52$, $p=0.66$) and postural condition effect ($F_{(1,100)}=0.11$, $p=0.74$) and any interaction.

Errors of memory guided saccades

Figure 3 reports the percentage of errors of memory-guided saccades. ANOVA showed a significant effect of the postural condition only: all children made significantly less errors of memory-guided saccades when they were standing up on platform than when they were sitting down ($F_{(1,100)}= 8.29$, $p<.004$, partial $\eta^2 = 0.23$). In contrast, ANOVA failed to show any group effect ($F_{(1,100)}= 2.35$, $p=.07$) and interaction ($F_{(1,100)}= 0.66$, $p=.057$).

Quality of fixation

Figure 4 reports the quality of fixation, showed by the number of saccades made during this task. ANOVA showed a significant effect of the groups ($F_{(3,100)}=10.12$, $p<.001$, partial $\eta^2 = 0.24$) and of the postural condition ($F_{(1,100)}=54.62$, $p<.001$, partial $\eta^2 = 0.36$), leading to poor fixation quality in the standing up on platform condition. The analysis also showed an interaction between groups and postural condition ($F_{(3,100)}=10.42$, $p<.001$, partial $\eta^2 = 0.24$). Precisely, the number of saccades during fixation was similar for children with ADHD and ASD but was significantly higher than in children with dyslexia or with a typical development (all $p<.001$ at the post hoc test). Children with dyslexia or with a typical development made similar number of saccades during the fixation condition. We finally observed an interaction between the presence of a neurodevelopmental disorder and the postural condition: children with ADHD and ASD showed poor fixation than the other two groups of children in sitting condition (both $p<.002$) and children with ADHD, dyslexia and ASD reported significant worse performance of the fixation task when they were standing up on platform (all $p<.003$). In children with typical development the postural condition did not influenced the fixation task.

In conclusion, latency of saccades was not affected by postural condition; in contrast, the percentage of errors for memory-guided saccades and the quality of fixation are differentially affected by postural condition given that standing up on platform improved the performance of memory-guided saccades, but on the other hand, deteriorated the quality of fixation in children with neurodevelopmental disorders.

Postural parameters

We also measured the postural parameters (Figure 5 and 6) in the three distinct visual tasks (visually-guided saccades, memory-guided saccades and fixations). ANOVA showed a significant group effect for the surface area and for the mean velocity of the CoP

($F_{(3,100)}=10.42$, $p<.001$, partial $\eta^2 = 0.24$ and $F_{(3,100)}=13.44$, $p<.001$, partial $\eta^2 = 0.30$, respectively). Post-hoc comparisons showed that both parameters were similar for the three groups of children with neurodevelopmental disorders but differed from those reported in children with a typical development (all $p<.003$). ANOVA failed to show any other significant effect of visual task ($F_{(2,100)}=0.09$, $p=.09$) and interaction ($F_{(6,100)}=0.09$, $p=.09$) for the surface area of the CoP. For the mean velocity of the CoP, ANOVA reported a significant visual task effect ($F_{(1,100)}=3.78$, $p<.02$, partial $\eta^2 = 0.28$) but no interaction ($F_{(1,100)}=0.77$, $p=.59$): the mean velocity was lower while children with neurodevelopmental disorders were performing visually-guided saccades with respect to memory-guided saccades and fixation (both $p<.01$).

In conclusion, analyses of CoP displacement reveal poor postural control in children with ADHD, dyslexia and ASD with respect to typically developing children; the effect of different visual tasks is observed in one parameter only, which is the mean velocity of the CoP.

Discussion

The goal of the present work was to study the interaction between posture and eye movements and to explore how a different eye movement task could affect postural sway in children. We demonstrate that (i) the parameters of eye movements were distinctively affected by postural conditions; (ii) the quality of fixation was poor in children with neurodevelopmental disorders compared to children with typical development when they are standing up on platform; (iii) the postural stability was decreased in children with neurodevelopmental disorders with respect to children with typical development.

The parameters of eye movements were differentially affected by postural condition

The present study reported that latency to a visual target and/or to a memorized target was not affected by posture. In contrast the percentage of errors in memory-guided saccades was affected by postural condition. Independently of the type of children tested, the performance of memory-guided saccades was improved when the child was standing up on the platform compared to the condition when she/he was sitting comfortable on a chair. Memory-guided saccades required the child to encode the spatial location of the target, to maintain the representation of that location across a delay period, and finally, make a volitional response to the remembered target (Pierrot-Deseilligny et al. 2003). Children with typical development and with neurodevelopmental disorders showed better performance of memory-guided saccades while they were in a challenging postural condition *i.e.* standing up on platform compared to sitting on a chair. During a dual task, children have to share their attention between the two distinct tasks, by dedicating more attention to the most challenging one. In our study, they mainly focused their attention to the memory-guided saccades task because the postural task could be executed in an automatic way, as suggested by the absence of postural parameters influenced by memory-guided saccade task.

The quality of fixation was poor in children with neurodevelopmental disorders with respect to typically developmental children when they were standing up on the platform

Visual fixation was a challenging eye movement type requiring recruitment of attention on the visual stimuli and inhibition of inappropriate eye movements. Our group already reported poor quality of visual fixation during a dual task in children with ADHD and dyslexia (see studies from Bucci's group cited in the Introduction section). However in this study, we explored for the first time three groups of children with neurodevelopmental disorders to typically developing children, and recorded simultaneously both eye movements and postural

performance. We observed that visual fixation was poor while the child was standing up on the platform and this condition discriminated typically developing children from children with neurodevelopmental disorders. Our findings provide additional evidence of the preliminary results reported by theoretical work of Plummer and Eskes (2015): they suggested that recording eye movements during postural task could be clinically relevant for a better diagnosis of children with neurodevelopmental disorders. Further studies in large samples of subjects from the general population, and also in patients with neurodevelopment disorders are required to confirm our results.

Our study suggested that children with neurodevelopmental disorders had low attentional resources to allocate to the most challenging dual task leading to poor performance. Both memory-guided saccades and fixation tasks were too much difficult task to be performed proficiently by children with neurodevelopmental disorders while they were standing up on the platform. In line with the U-shaped non-linear interaction model described by Huxhold et al. (2006), these children focused their attention on the postural task and not on the visual task leading to poor performance of the two visual tasks.

Several brain structures are activated during visual tasks including the frontal eye field (Goldberg et al. 1986), the posterior parietal cortex (Mountcastle et al. 1981; Shibutani et al. 1984) and the brain stem structures (Munoz and Wurtz, 1992). Doron et al. (2010) using diffusion imaging tractography showed also that prefrontal connections to the cerebellum are involved in the control of eye movements. Interestingly, studies investigating cortical modulation activity during dual task in healthy young subjects reported increased activities in parietal and frontal structures when the secondary task requests cognitive activities (Jensen and Tesche 2002; Ozdemir et al. 2016; Rosso et al. 2017). In light of our results, we hypothesized these neural structures could be impaired in children with neurodevelopmental

disorders leading to the difficulties to focus their attention on the secondary task in dual task conditions.

Postural stability was decreased in children with neurodevelopmental disorders

Our study expanded our previous work on postural stability in children with neurodevelopmental disorders (Bucci et al. 2017). Indeed, children with ADHD, dyslexia and ASD showed poor postural stability most likely due to a cerebellar dysfunction related to a deficiency into the cerebellar-cortical network (Stoodley et al, 2016). This hypothesis was recently reinforced by the study of Kim et al. (2017) in which children with ADHD showed a deficit in postural stability correlated to a decreased brain connectivity from the cerebellum to the premotor and the anterior cingulate cortex. Studies combining dual task and brain activities in children with neurodevelopmental disorders are needed to explore further cortical structures responsible of such poor postural control.

Finally we have to point out that the poor quality of fixation during sitting condition is the only parameter able to discriminate both children with ADHD and children with ASD with respect to children with dyslexia. In other word, children with ADHD and children with ASD show worse performance in visual attention capabilities. In line with the hypothesis of Stoodley (2016), cerebellar nuclei, respectively the bilateral and vermis that are deficient in children with ADHD and children with ASD could play an important role in controlling visual fixation.

Conclusion

This study reported similar visuo-postural deficits in children with neurodevelopmental disorders. Dual task condition could help to discriminate these children from those with

typical development. Children with neurodevelopmental disorders seemed to allocate insufficient attentional resources for performing correctly both tasks. Dual task situations measuring oculomotor and postural tasks simultaneously could be useful to delineate new and homogenous subgroups of patients and create new avenues for treatments. For instance, for children with neurodevelopmental disorders needing motor reeducation, we could develop new dual postural exercises that therapists can use to improve their motor control.

Author Contributions

MP Bucci : had primary responsibility for protocol development; prepared the draft of the ms

N Gouleme and D Dehouck: recorded and analysed the data; corrected the draft of the ms

C Stordeur, E Acquaviva and M Septier had primary responsibility for ADHD patient screening, enrollment; corrected the draft of the ms

A Lefebvre and R Delorme had primary responsibility for ASD patient screening, enrollment; corrected the draft of the ms

CL Gerard and H Peyre had primary responsibility for dyslexic patient screening, enrollment; corrected the draft of the ms

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Conflict of interests

The authors have no financial relationships relevant to this article to disclose.

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Table and Figures legends

Figure 1: Schematic diagram of the temporal arrangement used in three visual tasks A) visually-guided saccades, B) memory-guided saccades; C) fixation task.

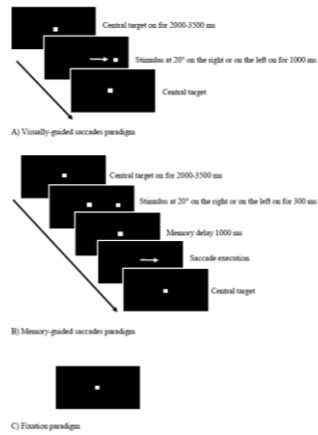


Figure 1

Figure 2: Latency values (in ms) of visually-guided (VGS) and memory-guided saccades (MGS) in the two postural conditions (sitting and standing up on the platform) for each group of children tested (ADHD, DYS, ASD and TD).

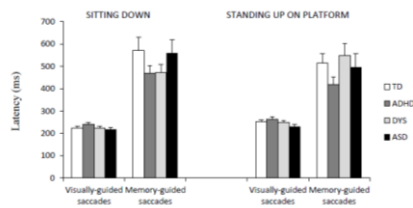


Figure 2

Figure 3: Percentage of the errors in memory-guided saccades in the two postural conditions (sitting and standing up on the platform) for each group of children tested (ADHD, DYS, ASD and TD).

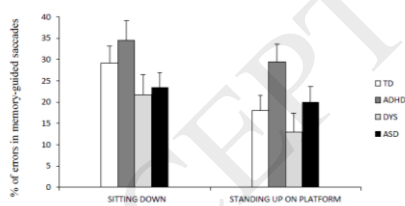


Figure 3

Figure 4: Number of saccades during the fixation task recorded in the two postural conditions (sitting and standing up on platform) for each group of children tested (ADHD, DYS, ASD and TD).

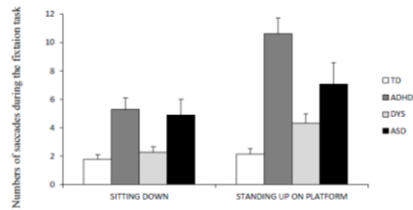


Figure 4

Figure 5: Surface area covered by the Center of Pressure (CoP) (in cm²) in the three different visual tasks (visually-guided -VGS- and memory-guided saccades -MGS- and fixation) for each group of children tested (ADHD, DYS, ASD and TD).

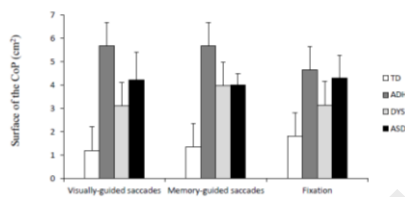


Figure 5

Figure 6: Mean velocity of the Center of Pressure (CoP) (mm/s) in the three different visual tasks (visually-guided -VGS- and memory-guided saccades -MGS- and fixation) for each group of children tested (ADHD, DYS, ASD and TD).

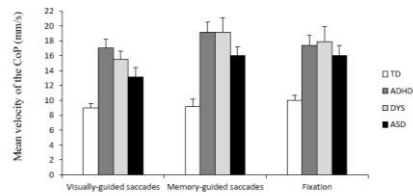


Figure 6

Table 1: Clinical characteristics (mean, std) of the four groups of children tested (ADHD, children with attention deficit hyperactivity disorder; DYS, children with dyslexia; ASD, children with autism spectrum disorders; TD, children with typical development). For the L2MA test done in children with dyslexia the standard deviation from normal mean is reported.

Table 1: Clinical characteristics of the four groups of children tested

	ADHD <i>N</i> = 26	DYS <i>N</i> = 26	ASD <i>N</i> = 26	TD <i>N</i> = 26
Age (years)	9.1 ± 0.3	9.5 ± 0.2	9.4 ± 0.1	9.5 ± 0.4
ADHD-RS total score	38.7 ± 1.7	5.6 ± 1.8	5.2 ± 1.1	4.8 ± 1.2
L2MA standard deviation from the mean				
<i>Oral Language</i>		2.8		
<i>Written Language</i>		2.6		
<i>Memory</i>		2.7		
Autism Diagnostic Interview-Revised (ADI-R) scores				
<i>Social Reciprocal Interaction</i>			18.5 ± 1.5	
<i>Communication</i>			12.5 ± 0.9	
<i>Stereotyped Patterns of Behaviors</i>			5.1 ± 0.5	
Autism Diagnostic Observation Schedule (ADOS) scores				
<i>Social Reciprocal Interaction</i>			8.4 ± 0.8	
<i>Communication</i>			3.9 ± 0.4	
Wechsler scale (WISC-IV) scores				
<i>Verbal Comprehension subscale</i>	100 ± 5	101 ± 6	101 ± 2	
<i>Perceptual Reasoning subscale</i>	98 ± 3	99 ± 4	97 ± 2	
<i>Working Memory subscale</i>	91 ± 4	93 ± 3	86 ± 4	
<i>Processing Speed subscale</i>	90 ± 5	89 ± 3	91 ± 3	
<i>Similarity test</i>	12 ± 2	12 ± 1	10 ± 2	12 ± 1
<i>Matrix reasoning test</i>	10.2 ± 1	11 ± 1	10.5 ± 1	10.8 ± 2