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ORIGINAL ARTICLE

Postural control among children with and without attention deficit hyperactivity disorder in single and dual conditions

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Abstract Given the known deficits in attention in attention deficit hyperactivity disorder (ADHD) and the evidence suggesting that postural control requires attention, this study aimed to investigate the mechanisms of postural control of children with and without ADHD in single-(ST) and dual-task (DT) conditions. Postural sway and stabilogram diffusion analysis (SDA) were performed on the Center of Pressure trajectories on 24 ADHD children and 17 age–gender-matched healthy controls. The subjects were instructed to stand as stable as possible on a force platform in two task conditions: (1) single task (ST) and (2) dual task (DT)—an auditory-memory attention-demanding cognitive task. During ST and DT conditions, the ADHD children showed significantly greater ML-sway, short- and long-term effective diffusion coefficients, and critical displacement of SDA compared with controls. The effects of DT were somewhat unexpected; the control group indicated a significant decrease in ML-sway, AP-sway, sway area, and critical displacement of SDA; the ADHD group showed a significant decrease in ML-sway range and critical displacement. It is *concluded* that a greater sway displacement before closed-loop mechanisms is called into play in ADHD children. The DT enhanced balance control by reinforcing balance automaticity and minimizing sway in both healthy and ADHD children.

Keywords Attention deficit hyperactivity disorder · Postural stability · Stabilogram diffusion analysis · Single task · Dual task

Introduction

Attention deficit hyperactivity disorder (ADHD) is a developmental disorder associated with difficulties in motor, academic, social, and emotional functioning [1]. Various studies have documented an association between motor coordination problems and ADHD [5, 16–18, 24, 26, 31, 32, 38, 40]. Children diagnosed with ADHD are often described as clumsy, having poor coordination, and suffering from improper fine and gross motor functioning [12–14, 39], having difficulties with attention focusing, and demonstrating impulsive behavior [1]. Sway velocity of ADHD children was significantly greater than that of healthy controls in upright standing [4], and the equilibrium scores in a sensory organization test were significantly lower than those of healthy controls [9].

Laboratory-based studies of balance control in ADHD have commonly been single task (ST) in nature, i.e., subjects can focus their cognitive attention on performing the motor task only. In a real life situation, however, the requirement to control balance occurs under more complicated circumstances, and cognitive attention is focused elsewhere (e.g., walking and talking or thinking). Postural control is not merely a reflex controlled task, but demands attentional resources that depend on the nature and complexity of the task, as well as the individual's age and balance capabilities [42]. Since postural control requires attention, we assume

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that children with ADHD will have difficulties controlling their balance in upright posture. Simultaneous performance of attention-demanding and balance tasks provides information that is different from that obtained from simple upright standing. This information could be interpreted in terms of automaticity of the acquired balance behavior as an essential characteristic of motor skills [22]. Most theories on cognitive function conclude that the available processing resources are limited [18]. As a result, resource competition may occur during the performance of more than one task, leading to task interference and difficulty in performing more than one task [22, 41, 42]. Most studies showed that the allocation of attention while standing increases sway [2, 25, 33]. However, these results are controversial. Children had significantly improved their postural stability in dual tasking but at the expense of reducing memory performance [28]. Riley et al. [27] have found that when participants performed the more difficult cognitive digit tasks (longer digit strings), postural sway was reduced relative to when performing an easy version of the task (few digits). Huxold et al. [10] found a U-shaped relationship between body sway and cognitive load for older adults, with increasing sway when there was no load or when cognitive load was very high. The effect of auditory attention-demanding cognitive tasks on motor performance in ADHD has been little studied, particularly with respect to postural control mechanisms. Study of ADHD children offers a unique opportunity for studying the contribution of attention to balance control.

In the present study, we compared the postural stability and balance control of children with ADHD to that of age–gender-matched controls under single- and dual-task (DT) conditions; in addition, we aimed to investigate the associations between the age and postural parameter as well as cognitive performance during DT in both groups. To the best of our knowledge, little research has yet been conducted to analyze and evaluate underlying mechanisms of postural control characteristics of ADHD children. Unfortunately, most studies use center of pressure (CoP) based summary statistics (e.g., traditional postural sway measures); these parameters, however, will not allow a more specific understanding of underlying postural control mechanisms. We used fractal measures such as stabilogram diffusion analysis (SDA) to discuss probable mechanisms of control strategies of balance control. Stabilogram diffusion analysis (SDA) [6] views CoP trajectories as a quasi-random walk and implements methods from statistical mechanics to better understand average sway behavior across various time intervals. The governing equation for this behavior defines a power law relationship between the mean-squared displacement of the CoP and the time interval over which those displacements occur. Stabilogram diffusion plots derived from CoP trajectories during upright stance indicate the presence of different behaviors depending on the time interval of interest. For shorter time intervals (~<1 s), the behavior is predominantly persistent, with the CoP tending to drift away from a relative equilibrium point (see Fig. 1). Longer time intervals are dominated by antipersistent behavior of the CoP, i.e., the CoP tends to return to a relative equilibrium point [6, 7]. It has been suggested that the short-term region reflects a behavior that, on average, is governed by open-loop control mechanisms, whereas the long-term region is governed by closed-loop control mechanisms [6, 7]. An open-loop control system operates without feedback, which, in the case of the human postural control system, could correspond to descending commands that set steady-state activity levels of postural muscles. Closed-loop control systems, on the other hand, operate with feedback and, in the case of the human postural control system, correspond to sensory information from the visual, vestibular, and somatosensory systems. The transition between the short-term and long-term behaviors has been termed the critical point; the coordinates of which would reflect the average time interval (critical time, Ct_j) and sway displacement (critical displacement, Cd) at which closed-loop control begins to dominate sway behavior. This interpretation and modeling framework enables one to relate SDA parameters to the steady-state behavior and functional interaction of the neuromuscular mechanisms underlying the maintenance of upright posture [6, 7].

The following hypotheses were tested in order to gain insight into the effects of ADHD on balance control: (1) While standing, ADHD children will show greater postural sway compared to controls given the known deficits in attention in ADHD and the evidence suggesting that

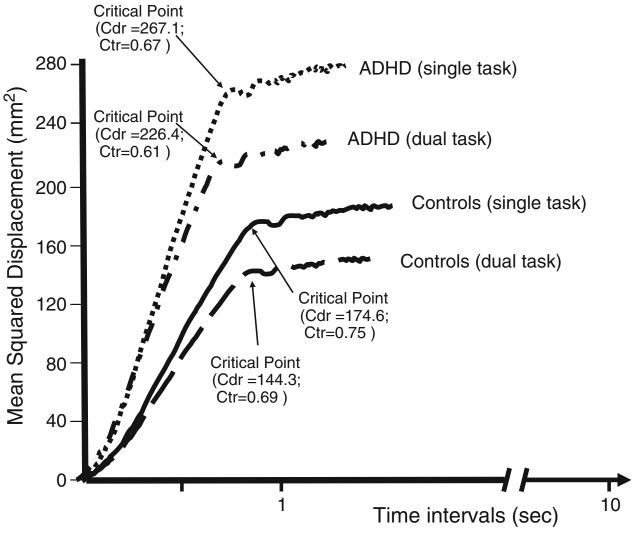

Fig. 1 Stabilogram diffusion plots. Experimental linear–linear stabilogram diffusion plots for ADHD in single- (*dotted line*) and DT (*dash-dot line*) conditions and controls in ST (*solid line*) and DT (*dashed line*) conditions. The computed short-term and long-term diffusion coefficients (in units of $mm^2 s^{-1}$) are shown for each group. Values are means±1 SEM

postural control requires attention. ADHD children will show greater sway displacement before closed-loop feedback mechanisms are called into play (e.g., increased short-term displacement). (2) During a concurrent auditory-memory attention-demanding cognitive task, postural sway of ADHD children and controls will be increased compared with ST condition due to task interference. Balance control in ADHD children will show a greater interference effect compared with controls. (3) It was hypothesized that the age, postural control parameters, and cognitive performance during DT would demonstrate moderate associations.

Methods

Study design and participants

The study group consisted of 24 ADHD children (9.3± 1.4 years old) who were diagnosed with ADHD in the Pediatric Neurology clinic at Soroka Medical Center, Beer-Sheva, Israel. A convenience sample of 20 age–gender-matched healthy control children (9.1±1.7 years old) was recruited from elementary- and middle-school populations (Table 1) in Beer-Sheva. Children's parents signed the informed consent, in accordance with procedures approved by the Helsinki Ethics Committee in Soroka Medical Center. As part of the initial assessment, all children, including the control group subjects, underwent a complete neurodevelopmental and motor screening evaluation by an experienced pediatric neurologist using the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) diagnostic criteria [1]. Diagnosis of ADHD was based on interviews with the parents and children, clinical examination, and Conners' parent and teacher questionnaires [8]. ADHD symptoms had to be severe for six or more items on the DSM-IV ADHD rating scale (ADHD RS-IV) parent version, which was administered to the parents by an experienced pediatric neurologist. The parental ADHD RS-IV contains nine attentive and nine hyperactive/impulsive items. Teachers returned a personally completed version of this rating scale by mail. If at least six core DSM-IV ADHD symptoms were rated "very often" among the nine attentive items, a child was classified as the inattentive ADHD type. If six or more items of the nine inattentive items and six or more items of the nine hyperactive/impulsive items are fulfilled, a child was classified as combined type. The hyperactive/impulsive type was not represented in this study population. Three of the 20 "healthy" control group children who volunteered for the study were diagnosed with ADHD; thus, they were excluded. Eligibility criteria were children who were 8–15 years old and treated by MPH on a daily basis for at least 3 months prior to the study. To ensure ADHD deficiency, only children with good clinical response with an improvement of ADHD symptoms after MPH treatment according to the parents' and teachers' reports on the ADHD RS-IV questionnaire and according to the pediatric neurologist's follow-up were included in the study. Exclusion criteria were ADHD children who were diagnosed with neurological, orthopedic, or psychiatric diagnoses according to DSM-IV criteria that can affect motor control and postural stability; cerebral palsy; neuropathic diseases; limb fracture; head trauma during the previous year; use of any medication other than MPH during the study period; and those who had an IQ score below the normal range (<70), as assessed by the Wechsler Intelligence Scale for Children–Revised (Wisc-R) administered by a child psychologist. All of the children were enrolled in age-appropriate grades in mainstream schools.

Postural stability protocol

The subjects were instructed to stand upright as still as possible on the force platform with the feet positioned as close as possible (heels and toes touching). A total of five 30-s quiet-standing trials were obtained from each participant instructed to stand as still as they possibly can in two task conditions. Two-minute rest breaks were provided between two task conditions, and 30-s rest breaks were provided between trials. The two task conditions were (1) single task (ST)—standing upright viewing an "X" displayed on a screen 3 m in front of them—and (2) dual task (DT)—same as (1) while performing an auditory-memory-demanding task. During this task condition, the children were also instructed to listen to a collection of different sets of six children's songs, each lasting for 5 s. The children were instructed to try and memorize the songs while standing still. After the completion of each of the 5 trials, a list of 15 children's songs was shown to the children, and their task was to recall from the list which songs they had heard during the last trial. The number of mistakes was counted in each of the five trials and presented as an average number of mistakes in all trials. On the day of the experiment, the ADHD children were off MPH medication prior to the experiment, which means that they had at least 24 h without MPH administration. The duration of action of MPH is 3–5 h [37]; therefore, the drug's influence is negligible after 24 h.

Balance measurements were collected with a Kistler 9287 single force platform (Kistler Instrument Corp., Winterthur, Switzerland) that measures the time-varying displacement of the center of pressure (CoP). The force platform data were sampled at a frequency of 100 Hz and stored on a hard disk for later processing. Four well-established parameters of postural stability were extracted using automatic code written in Matlab (Math Works Inc., Cambridge, MA, USA): (1) medio-lateral CoP range (mm) (ML-sway range), (2) anterioposterior CoP range (mm) (AP-sway range), (3) mean velocity of CoP sway (mm/sec), and (4) sway area (mm^2)—the elliptical area

Table 1 Characteristics of ADHD and controls. Values are means±1 SEM

Characteristic, mean ± SEM	ADHD	Control
Age (years)	9.3±1.4	9.1±1.7
Gender (female/male)	2/22	2/15
Weight (kg)	31±1.6	29.7±1.2
Height (m)	1.35±0.02	1.33±0.02
Single task		
Traditional postural stability parameters		
ML-sway range (mm)	40.7±2.1[a]	33.8±1.6
AP-sway range (mm)	35.6±2.7	30.6±1.4
Mean velocity (mm^2/s)	29.9±1.4	27.9±1.4
Sway area (mm^2)	158.4±15.3	132.5±9.7
Stabilogram diffusion parameters		
Short-term effective diffusion coefficients in mm^2 s^{-1} (Drs)	33.2±7.9[a]	13.99±2.5
Long-term effective diffusion coefficients in mm^2 s^{-1} (Drl)	9.1±2.8[a]	4.2±1.1
Critical time intervals in sec (Ctr)	0.67±0.07	0.75±0.07
Critical displacement in mm^2 (Cdr)	267.1±1.3[a]	174.6±13.2
Dual task		
Traditional postural stability parameters		
ML-sway range (mm)	37.9±2.1[a,b]	31.4±1.6[b]
AP-sway range (mm)	37.3±3[a]	28.5±1.4[b]
Mean velocity (mm^2/sec)	29.8±1.6	26.9±1.3
Sway area (mm^2)	146.9±15.6	121.1±10.7[b]
Stabilogram diffusion parameters		
Short-term effective diffusion coefficients in mm^2 s^{-1} (Drs)	41.3±11.1[a]	12.4±2.9
Long-term effective diffusion coefficients in mm^2 s^{-1} (Drl)	6.1±1.2[a]	2±0.5
Critical time intervals in sec (Ctr)	0.61±0.07	0.69±0.07
Critical displacement in mm^2 (Cdr)	226.4±29.7[a, b]	144.3±12.7[b]

mm millimeters, *mm^2* millimeter squared, *sec* seconds, *mm^2/sec* millimeters squared/second

[a] Between groups ($P<0.05$)

[b] Between task conditions within groups ($P<0.05$)

of the CoP points. Lower postural stability scores indicate higher levels of postural control. Also, four parameters of SDA were extracted using automatic code written in Matlab: (1) short-term diffusion coefficients in square millimeters per second (Drs), (2) long-term diffusion coefficients in square millimeters per second (Drl), (3) the critical time in seconds (Ctr), and (4) critical displacement in centimeters (Cdr). These parameters were computed for each subject's trials and then averaged for each set of five trials to obtain an average value for each parameter and for each subject, in each experimental condition.

Sample size

To test the first hypothesis, we used data presented by Cheng and Wang [4] that examined postural control between 9 and 10-year-old, healthy, and ADHD boys standing on a firm surface with eyes open. The mean sway velocity recorded within each subject group was normally distributed, with a standard deviation of 0.19. The difference between the experimental and control means was 0.18 cm/s. Using these numbers for a two-sided estimation at a significance level of 0.05 and 80% power, it was calculated that a minimum of 19 children in each group would be required to find significant differences. To test the second hypothesis, the sample size estimation was based on data presented by Schmidt et al. [30] who have shown that the mean velocity of postural sway in children was 0.17±10 cm/s with no cognitive task, whereas the mean velocity of postural sway of the same children during a concurrent cognitive task was 0.26±10 cm/s. For a conservative estimation, we have used a standard deviation of 0.10 of their work. Using the aforementioned numbers for a two-sided estimation at a significance level of 0.05 and 80% power, it was calculated that a minimum of 12 children in each group would be required to find significant differences.

Statistical analyses

Descriptive statistics are reported as mean ± SEM. We used independent *T*-tests to compare the ADHD and controls with respect to different characteristics (age, weight, height, and number of memory task errors made during the auditory-memory attention-demanding tasks). Since traditional postural stability parameters (ML-sway range, AP-sway range, mean sway velocity, and sway area) and SDA parameters (Drs, Drl, Ctr, and Cdr) were not normally distributed (Shapiro Wilk statistic), non-parametric statistics, Mann–Whitney *U*-test was performed to compare the differences between groups (ADHD vs. control), and Wilcoxon signed rank test was used to compare task conditions (ST vs. DT). A significance level of 0.05 was used.

To test the interference effect of DT, independent *t*-test was used to evaluate the overall interference effect of the concurrent attention-demanding task (the average value across dual-task trials normalized to single-task trials within each group) on ML-sway range and critical displacement, between the two age groups. A significance level of 0.05 was used. All data analyses were performed using SPSS for Windows (version 15, Chicago, IL).

In respect to postural stability measures, one way ANOVA with additional post hoc analysis (LCD) was measured to explore statistically significant differences between five trials. In addition, relative reliability, or the stability of the postural parameters between five trials given the inherent inter-trial variability, was quantified using the intraclass correlation coefficient (ICC). The following guidelines were used when interpreting ICCs: $ICC<0.4$ represents poor reliability, $0.4\leq ICC\leq 0.75$ represents fair to good reliability, and $0.75\leq ICC$ represents excellent reliability. Also, spearman correlations (rho) were administered to explore associations between the age and postural parameter as well as cognitive effect. The following guidelines were used when interpreting correlation magnitudes: 0.00–0.25 represents no correlation to little correlation, 0.26–0.49 represents low correlation, 0.50–0.69 represents moderate correlation, 0.70–0.89 represents high correlation, and 0.90–1.00 represents very high correlation.

Results

Subject characteristics

Forty-one children participated in the study, 22 ADHD boys and 2 ADHD girls aged 9.3±1.4 years and 17 (15 boys and 2 girls) control children aged 9.1±1.7 years with no ADHD (Table 1). Table 1 describes the characteristics of the participants. There were no significant age, weight, height, and gender differences between groups. In respect to postural stability measures, one way ANOVA with additional post hoc analysis (LCD) revealed no statistically significant differences between trials. The results show that sway parameters are mostly consistent across trials; the ICC measure of five trials with eyes open was moderate for Cdr=0.72, Ctr=0.54, and sway area=0.69; high for Dsr=0.85, ML sway=0.79, and sway velocity=0.89; and low for Drl=0.2 and AP sway=0.44.

The effect of ADHD

Table 1 and Fig. 1 show that ML-sway range was significantly larger for ADHD children compared with controls in ST ($P=0.011$). In DT condition, the ML-sway range and AP-sway range ($P=0.016$ and $P=0.015$, respectively) revealed significantly higher values in ADHD children compared with controls.

The SDA parameters during ST condition demonstrated significantly greater values in short-term effective diffusion coefficients (Drs), long-term effective diffusion coefficients (Drl), and critical displacement (Cdr) in ADHD children compared with controls ($P=0.03$, $P=0.01$, $P=0.03$, respectively) (Table 1 and Fig. 1). Similarly, during DT condition, Drs, Drl, and Cdr were significantly greater ($P=0.018$, $P=0.003$, $P=0.016$, respectively) in ADHD children. Critical time intervals (Ctr) were not different between groups in both task conditions.

ADHD and control children did not differ in the number of memory task errors of the auditory-memory attention-demanding cognitive task of the DT condition (2.35±1.3 vs. 2.1±0.8, respectively, $P=0.6$).

Effects of cognitive task

For DT compared to ST, during the concurrent auditory-memory attention-demanding cognitive task, ADHD children showed a significantly lower value in ML-sway range ($P=0.035$). The control children show significantly lower sway area, ML-sway range, and AP-sway range in DT compared to ST conditions ($P=0.02$, $P=0.01$, and $P=0.01$, respectively).

ADHD children demonstrated significantly lower critical displacement (Cdr) during DT compared with ST condition ($P=0.01$), while Drs, Drl, and Ctr were not significantly different (Table 1). Control children showed similar results for DT compared to ST; the Cdr was significantly lower ($P=0.001$), and the Drl was marginally lower ($P=0.08$).

Figure 2a, b shows a ratio between dual- and single-task test conditions for traditional postural sway and stabilogram diffusion analysis measures for the two groups. A fairly similar non-significant between-groups “interference effect” can clearly be noted.

Relations between age, postural control, and cognitive function during DT

ADHD children demonstrated no to little correlation between age and number of cognitive task mistakes during DT ($r=-0.28$), while healthy control subjects demonstrated a moderate significant correlation ($r=-0.58$). ADHD children demonstrated low significant correlations between age and postural control parameters in ST condition (ML-sway, $r=-0.41$; AP sway, $r=-0.45$; sway velocity, $r=-0.46$) and a

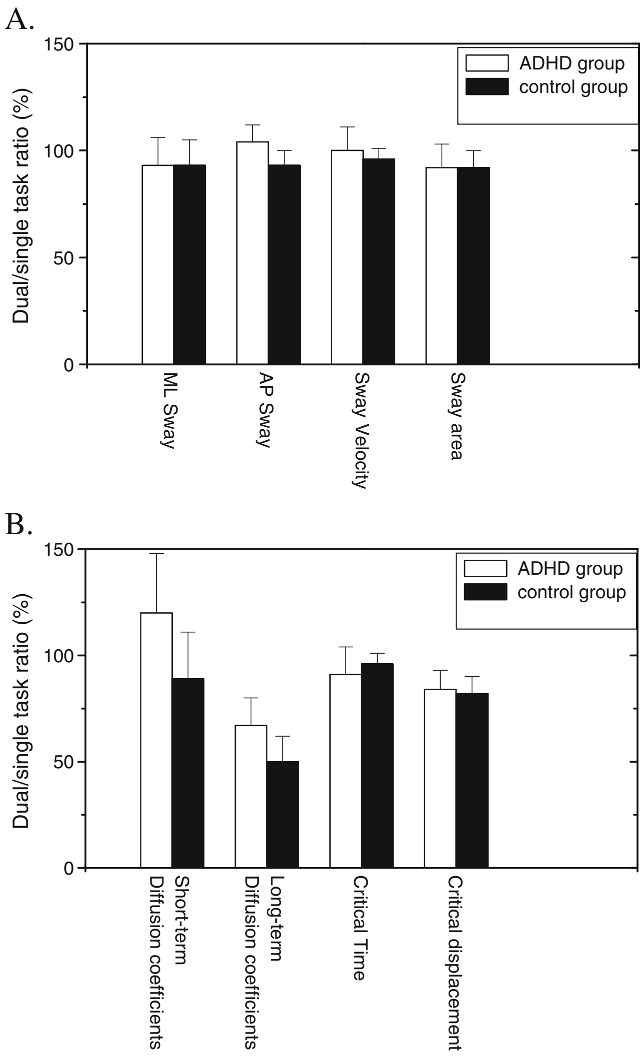

Fig. 2 The interference effect of an auditory-memory attention-demanding cognitive task in ADHD and control subjects on **a** postural sway parameters and **b** stabilogram diffusion analysis parameters (dual task normalized to single task). The values represent ratios in percentages±1 standard deviation of the average value of all trials in dual task/the average value of all trials in single task. Note: there were no significant differences between groups

moderate correlation in DT condition (Cdr, $r=-0.57$; AP sway $r=-0.53$; sway velocity, $r=-0.62$; and sway area, $r=0.59$). Healthy control subjects showed a moderate correlation between age and postural control parameters in ST condition (Cdr, $r=-0.51$; Drs, $r=-0.52$; Drl, $r=-0.51$) and similar during DT condition.

Discussion

In this study, we sought to quantitatively compare effects of a concurrent auditory-memory attention-demanding cognitive task on postural stability and balance control mechanisms between ADHD children and age- and gender-matched controls. The results support our first hypothesis; we found greater postural sway in ADHD children compared with controls under both task conditions. Evaluation of the underlying mechanism of postural control characteristics using SDA showed a significant increase in Drs, Drl, and Cdr in ADHD children in both task conditions. The greater values for Drs for the ADHD children indicate greater short-term (open-loop control) stochastic activity (greater amplitude and/or frequency of the random walker). The increased Cdr is an indication of greater sway displacement in the ADHD before closed-loop feedback mechanisms are called into play. This can result from an increase in the threshold of peripheral sensory receptors detecting postural sway; another explanation might be an inability to pay attention to the motor single task of minimizing sway due to a cerebral dysfunction in ADHD.

Consequently, the results suggest that the mechanisms of postural control were affected by attention deficit disorder. Since ADHD children and their non-affected siblings showed similar tactile perception and unimpaired kinesthesia [29], it is unlikely that the increase in postural sway displacement before closed-loop in ADHD resulted from reduced peripheral sensory feedback. A cerebral dysfunction, however, was related to slower central processing abilities in ADHD, which was assumed to be, in part, the result of dopaminergic depletion [3, 19]. Impaired dopamine uptake in the basal ganglia of ADHD children suggests that it plays a central role in the altered balance in ADHD children; this may be the primary source of the increased critical displacement (Cdr) until closed loop feedback balance control is called into play, which is compatible with the slower central processing hypothesis. Morphological neuroimaging studies have demonstrated that children with ADHD have reduced volumes in the caudate nucleus, frontal lobes, and prefrontal cortex, with the latter two being areas in the brain that play an especially important role in executive function and attention [3, 35, 45]. Other brain imaging studies indicate that balance control deficits could also be of cerebellar origin as ADHD children show atrophy in those regions of the cerebellum associated with gait and balance control [21]. In this case, it is reasonable to suggest that differences in the activation of postural corrections found in our study could result from lower capabilities and/or inability to focus attention on a specific task.

Contrary to our second hypothesis, the concurrent auditory-memory attention-demanding cognitive task used in the current study did not have a negative interference effect on postural control in either ADHD or controls. When comparing DT and ST conditions, ADHD children showed lower values of ML postural sway range and Cdr, and controls showed lower values in sway area, ML-sway range, AP-sway range, and Cdr, indicating engagement of closed-loop control mechanisms at smaller sway amplitudes.

The use of DT paradigms to examine the attentional requirements of balance control when performing a secondary task has commonly shown that they cause increased instability [20, 23, 33, 34] with secondary cognitive tasks producing interference, with the most difficult cognitive task having the greatest influence on balance parameters [15]. Yet, Yardley et al. [44] found that a silent counting task had no interference effects on stability in young adults. Swan et al. [36] found that spatial and non-spatial memory tasks produced improvement in postural sway. Similarly, in the current study, postural sway was reduced in DT compared with ST condition in both ADHD and controls, suggesting improved control of balance during an auditory-memory attention-demanding cognitive task. Explanations for the apparent improvement in sway parameters seen under DT conditions could be that the ST of actively controlling posture is too difficult for children. Consequently, when their attention is focused on a secondary task not related to sway control, their performance may actually improve.

The better performance in DT condition can be explained by the possibility that focusing one's attention exclusively on balancing (the ST standing still task) is actually detrimental to balance task performance. Children in the present study may be constantly over-correcting their balance back and forth for even minor balance disturbances, "searching" for a stable position, thereby increasing sway parameters. Shifting their attention over to the DT may "relax" their postural control behavior. Thus, the additional cognitive load required under the auditory-memory attention-demanding cognitive task leads to a more automatic control mode of balance. If children are unable to voluntarily provide the fine-tuning control required to minimize sway (task too hard for their skill/developmental level), then they would perform better if attention is taken away from posture and control is more automatic. This is consistent with the constrained action hypothesis; according to which, an external focus promotes the use of more automatic control processes; this may improve postural control [43]. The current study showed that accuracy on a memory task was not different between ADHD and controls, suggesting that both groups directed sufficient attentional resources to the cognitive task. That would also mean that resources were shifted away from the postural task during the auditory-memory attention-demanding cognitive task, further supporting the concept that a more automatic mode for control of balance dominated behavior under the DT condition. The DT/ST ratios show that the children with ADHD did not benefit more from the dual task than non-ADHD children during balance control. These strengthen our conclusions suggesting that balance problems in children with ADHD do not depend on attentional resource allocation but rather on different central processing.

This study has several limitations. First, memory performance during sitting was not examined, so we do not know if there was an interference effect of the motor task (standing balance) on cognitive performance (memory task). Thus, we do not know whether children with ADHD and controls utilize cognitive resources differently in the balance task and memory task (i.e., task prioritization). Secondly, DT testing was always performed after the ST testing procedure. One could argue that practice, learning of the balance task, and/or familiarity with the setup produced the reduced postural sway during the DT. However, the results from a previous study [11] showed that MPH treatment brought about a significant reduction in postural sway, not seen in the placebo MPH group, suggesting that practice, learning, and task familiarity do not influence repeated measures of postural stability. Thus, it seems likely that the secondary task, not practice, was responsible for the observed reduction in postural sway. Third, the data came from a fairly small sample that was drawn from a defined ADHD and healthy control population; these results cannot be generalized to other pediatric neurological conditions. Finally, we did not find negative effect of dual task on postural control; we assume that the cognitive task that was chosen was too simple. Larger scale studies among the various subtypes of ADHD and other pediatric conditions (e.g., CP) are needed. These studies are required to investigate effects of a different cognitive load tasks on gait and balance function in ADHD and whether this is affected by MPH. In conclusion, our findings provide evidence linking attentional demands and closed-loop mechanisms of balance control. Regardless of the precise explanation, the effect of simple dual tasking can be viewed as improving balance performance, with no significant effects on the cognitive performance. This supports the idea that a simple concurrent attention task contributed to the improved balance control in children. As noted previously, this could also largely account for enhanced balance control by reinforcing balance automaticity and minimizing sway. But, other mechanisms may have also played a role; some might speculate that additional simple cognitive load increases dopamine release in the brain which is known to improve motor performance.

Conflict of interest The authors declare that they have no competing interests and no financial relationship with the organization that sponsored the research.

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