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Effects of visual search vs. auditory tasks on postural control in children with autism spectrum disorder

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ABSTRACT

Recent research in motor control shows the interactive role of cognitive factors in postural control. However, there is little understanding in how children with autism spectrum disorder (ASD) develop their postural behaviors. This study compares the interference of visual or auditory tasks on postural control in children with ASD. We examined 19 children with ASD (10–15 years old) and also 28 age-matched typically developing (TD) children. They were asked to perform two tasks during postural control: (1) a visual searching task (2) an auditory digit span task. Postural performances were measured with a force platform. Results showed that children with ASD indicated higher postural sway scores in visual task vs. auditory task; as root mean square ($p = 0.04$), mean velocity ($p = 0.01$) and sway area ($p = 0.02$) but TD children scores remained unchanged. Children with ASD also showed significantly higher sway scores than TD children in all parameters. We conclude that in addition to primary differences in patterns of postural control of children with ASD compared to TD children, visual and auditory tasks may differently influence the postural control in this population.

1. Introduction

Autism spectrum disorders (ASD) are a group of child onset neurodevelopmental disabilities which approximately affect 1 in 88 children [1]. The diagnosis of ASD requires impairments in three domains of sociability, language, and behaviors; however, there are other clinical presentations which should be taken into account. Children with ASD usually experience a few problems in fine and gross motor skills such as motor clumsiness, lack of coordination and motor planning which involve the performance of gait and posture [2,3]. Recent studies showed that children with ASD are more posturally instable in the bipedal stance than their typically developing (TD) peers [4–6]. Impairments in brain structures and cognitive functions as well as sensorimotor integrations, may be associated with their higher postural instability [7]. Research indicates that motor impairments similar to abnormal reactions to sensory stimuli [7,8], and cognitive deficits [9] are the most common early symptoms in children with ASD. Thus it is suggest that motor assessment is needed as part of the early clinical assessment in ASD [2].

In most real life situations, postural control is usually accompanied by at least one posture unrelated task (e.g., visual or auditory manipulations) [10]. Indeed maintaining postural control needs to allocate sufficient attention resources to motor, cognitive or sensory stimuli from the context [10,11]. To investigate cognitive mechanisms underlying postural control, a concurrent cognitive task during postural examination (i.e., dual task) is frequently used. When two tasks are involved, there is every likelihood that the attention will be divided between the two [10,12]. Investigating participants in several conditions of different attentional demand (e.g., digit reversal or counting backward by 3 s); Pellecchia showed that postural sway scores would increase when attentional demands of the cognitive task were more challenging [13]. However further study using a memory task in 20 healthy individuals revealed that increased cognitive load of the task would decrease postural sway variability independent of sensory manipulations [14]. Furthermore, Vuillerme et al. discussed that distraction from a motor task such as locomotion (using a dual cognitive task) resulted in more

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accurate performance (i.e., smaller deviations) in contrast to the condition participants had to concentrate on their motor task [15].

Considering the variations of methodology (e.g., type of tasks or conditions), these findings seem not to be directly contradictory due to the context of their studies [10,11]. However a few questions remain unsolved such as the role of specific conditions, sensory manipulations or cognitive abilities in influence of secondary task on postural control of healthy individuals but particularly those with sensory or cognitive impairment (such as ASD).

According to a recent study, children with developmental coordination disorders experience higher postural instability in dual task condition. They were asked to name the objects appearing on the screen while maintaining a bipedal stance [16]. Similarly, children with Tourette syndrome scored lower in postural stability than TD participants while doing visual tasks [17]. They may switch priority to the cognitive tasks and allocate more attentional resources to it rather than postural perormance [16]. In a rare studies of this kind, Chang et al. documented that children with ASD show more postural sway while executing inspection task compared to searching visual task [18]. Indeed they revealed a preliminary result on postural control in ASD affected by visual manipulations but did not comprehensively explain underlying mechanisms.

To provide more explanation Riley et al. examining auditory and visual tasks in postural control of healthy individuals showed that postural control changes would be sensitive to modality of information presentation [14]. Although the finding was not replicated [19], it seems that since visual inputs provide vital information for postural control, the task with higher visual dependency may decrease postural control ability more than the tasks with lower visual properties [20]. Furthermore, imaging findings indicate a brain network including temporoparietal junction (TPJ) responsive to changes in visual and auditory stimuli during a dual task experiment. The TPJ abnormalities are also evidenced in ASD [21]. As children with ASD have higher dependency to visual information, they may show higher level of interference performing a concurrent visual task compared to TD counterparts. Although there is an agreement on general impairment of postural control in ASD, little attention has yet been paid to study the underlying processes (e.g., cognitive or sensory) on their postural control. In that vein, examining the influence of different sensory modalities on postural control may help to know whether there are different patterns in how a visual or auditory task may affect postural control in children with ASD.

In the current study, we examined the effect of a concurrent visual task vs. an auditory task on the postural control in children with and without ASD. We hypothesized that visual task shows higher interaction with postural control than auditory task in ASD. We also expected that generally, children with ASD show higher postural sway scores compared with TD children.

2. Methodology

2.1. Participants

The study group consisted of 19 boys (10–15 years old) diagnosed with high functioning ASD (IQ > 80). The diagnosis of ASD was based on both DSM-IV and the autism diagnostic inventory-revised (ADI-R) by a child psychiatrist. Study was announced in autism specific schools in Tehran then children were recruited from grades 1 to 5. They were excluded if known to have significant behavior problems, uncontrolled seizures, visual or auditory impairments, using postural assistive devices and not able to count from 1 to 20. Furthermore, 28 age matched TD boys were recruited from two community schools in same area and served as controls. They were excluded if determined to have neurological or musculoskeletal problems and vestibular, auditory or visual impairments. Children in two groups were also matched for non-verbal IQ. Children's parents provided informed written consent and each child verbally agreed to participate in the experiment. The study was approved by the Medical Ethics Committee of Tehran University of Medical Sciences.

2.2. Measurements

2.2.1. Assessment of postural control

We sampled center of pressure (COP) displacements with the Bertec force plate (Model 4060-10, Columbus, OH) at 200 Hz. The sensors under the force platform record the position of ground reaction forces and register the data in a computer. Force platform was calibrated at the beginning of each trial. Then, we calculated the postural sway parameters, root mean square (RMS), mean velocity (MV) and sway area (SA) using excel macros.

RMS in essence is the standard deviation of COP replacements based on the mean location. The parameters were presented as composite (Simply as RMS), anteroposterior (RMS $_{\text{AP}}$), mediolateral (RMS $_{\text{ML}}$) scores [22]

$$\mathrm{RMS_{AP}} = \sqrt{\frac{\Sigma_{n=1}^{N}(X_n - X_{\text{mean}})^2}{N}},$$

$$\mathrm{RMS_{ML}} = \sqrt{\frac{\Sigma_{n=1}^{N}(Y_n - Y_{\text{mean}})^2}{N}},$$

$$\mathrm{RMS} = \sqrt{\frac{\Sigma_{n=1}^{N}[(X_n - X_{\text{mean}})^2 + (Y_n - Y_{\text{mean}})^2]}{N}}$$

Mean velocity is the average speed that COP travels and is calculated by dividing the total displacement to the duration of each trial [22]. The parameters were presented as composite (simply as MV), anteroposterior ($\mathrm{MV_{AP}}$), and mediolateral ($\mathrm{MV_{ML}}$) scores

$$\mathrm{RMS_{AP}} = \frac{\Sigma_{n=1}^{N-1}\sqrt{(X_{n+1} - X_n)^2}}{T},$$

$$\mathrm{MV_{ML}} = \frac{\Sigma_{n=1}^{N-1}\sqrt{(Y_{n+1} - Y_n)^2}}{T},$$

$$\mathrm{MV} = \frac{\Sigma_{n=1}^{N-1}\sqrt{(Y_{n+1} - Y_n)^2 + (X_{n+1} - X_n)}}{T}$$

Sway area is the area covered by COP sway per unit of time [23]. Then the parameter was presented only as composite score

$$SA = \frac{1}{2T}\sum_{n=1}^{N-1}\left(\left|Y_{(n+1)} * X_{(n)} - Y_{(n)} * X_{(n+1)}\right|\right)$$

Apparently, the smaller amplitude of the sway parameters shows higher postural stability. (Note: T stands for trial duration, X and Y are time series for anteroposterior and mediolateral directions, respectively; n is data point of interest, and N is the total number of data points.)

2.2.2. Procedure

Background information of children was collected by the relevant checklists. Each child's postural control was assessed in a quiet room with two testing conditions. During examination, to limit visual distracters, protected walls were placed around the force plate and children were asked to keep their feet in designated areas marked on the plate in order to use the similar foot positions between different conditions. Prior to data collection, each child had been presented with the items printed on the paper in order to ensure that the child could search, identify and count them easily for the visual task. Also, before the main experiment cognitive capacity of each child for digit span task was determined. When the main experiment commenced, children were requested to stand as straight as possible with no shoes on the force plate, arms at their sides and performing visual searching in one condition and digit span task in another.

In the first condition, children were asked to search and count silently the total numbers of specific geometrical items among others printed on a paper (with size of 16.5 inch × 11.7 inch). The paper contained 20 items of four different forms (square, circle, triangle, rectangular). The paper was stuck on the wall 40 cm far from the examinee and adjusted to each child's eye level. If the child finished the counting of specific items, he was requested to count another item in order to be kept busy throughout the task. The second condition, digit span task, required participants to hold a string of random digits in mind and then rehearse it in the same order during standing on the force plate and looking directly at a marker. The marker was 40 cm far from examinees and was adjusted to their eye levels. We used this marker to fix the eyes and prevent possible deviations of the head.

Participants were required to perform two trials per condition each lasted for 30 s with 1 min rest interval [16]. About the trials with challenging behaviors (e.g., stereotypical movements) or loss of focus, those were excluded and replaced by extra ones, though three children have been re-tested a week later.

2.3. Statistical analysis

The first and the last 5 s of each trial were eliminated and the average of data from two trials was computed as providing the one representative data for each participant's condition. Postural sway parameters were then calculated based on the formulas. The normal distribution of data was confirmed by Kolmogorov–Smirnov test. Differences of postural sway among conditions (visual against auditory task) in ASD compared with TD group were tested by ANOVA for repeated measures. In this case, each sway parameter was tested separately. If any interaction was found significant, we carried out a separate paired *t*-test analyses for each group. All statistical tests were performed using SPSS software version 17 (SPSS Inc., Chicago, IL, USA). The level of significance was set at $p < 0.05$.

3. Results

Table 1 illustrates some of the main characteristics of the participants. Analysis of data showed that there were no significant differences in background variables between the two groups. Results of repeated measure ANOVA for sway parameters across visual vs. auditory task conditions are presented below.

3.1. Root mean square

Analysis of combined data indicated that there was a significant main effect of condition for RMS ($F(1, 45) = 5.88$, $p = 0.01$) and also RMS_{ML} ($F(1, 45) = 4.60$, $p = 0.03$). The interaction effects (Condition × Group) were only significant for RMS (Table 2). Pair *t*-test analysis on each group revealed that RMS scores in children with ASD were significantly greater at visual task than at auditory task (95% CI: 0.003–0.517, $p = 0.04$), whereas TD children remained similar across the conditions ($p = 0.69$).

Table 1
Characteristics of children in ASD and TD groups.

	ASD $\mu \pm$ SD	TD $\mu \pm$ SD
Age (Y)	11.9 ± 1.6	11.8 ± 1.7
Height (cm)	157.1 ± 10.9	159.7 ± 12.5
Weight (kg)	46.3 ± 11.6	49.7 ± 14.2
Non-verbal IQ	94.3 ± 9.1	97.6 ± 7.6
Child grade	4.8 ± 1.2	6.4 ± 1.7

Note: Mean (μ) and standard deviation (SD) of variables, ASD (autism spectrum disorders), and TD (typically developing children).

3.2. Mean velocity

As can be seen from Table 2, there was a significant main effect of condition only for MV_{AP} ($F(1, 45) = 4.14$, $p = 0.04$). Furthermore, the interaction of condition and group were also significant for MV and MV_{AP}. Pair *t*-test indicated that ASD group showed significantly higher scores of MV_{AP} at visual than auditory task condition (95% CI: 1.57–8.33, $p = 0.006$) but control group did not ($p = 0.29$). MV scores in ASD group increased at visual compared with auditory task condition but not significantly ($p = 0.07$).

3.3. Sway area

There was a significant main effect of condition for SA ($F(1, 45) = 6.21$, $p = 0.01$). The interaction between condition and group was also significant (Table 2). Further analysis showed although in TD children, SA differences between conditions was subtle ($p = 0.75$), children with ASD showed a significant greater scores at visual than auditory task condition (95% CI: 2.21–36.25, $p = 0.029$).

Furthermore, the graphical changes of postural sway parameters in each condition are shown in Fig. 1. As data shows, children with ASD indicated higher postural sway compared with TD participants in all sway parameters.

4. Discussion

This study for the first time has aimed to investigate the possible effects of visual and auditory tasks on postural control in children with ASD compared with TD children.

Expectedly, children with ASD showed higher postural sway in all conditions compared with their TD counterparts. This finding is well in line with previous studies demonstrating difficulties of children with ASD in sensorimotor processing [8] which contributes to a number of motor dysfunctions [4,7]. Furthermore, neuroimaging studies among individuals with ASD showed that structural and functional impairments in cerebellum and basal ganglia affects their abilities in keeping the posture upright [24]. Consequently, these individuals are less developed in the motor skills and fall behind their TD peers in maintaining their upright postures against any postural perturbations. Additionally, based on limited attentional capacity, children with ASD who have reduced attentional resources show higher postural instability when dividing the cognitive resources with a secondary task compared with TD counterparts [11].

As a notable finding, the current study showed that individuals with ASD exhibit more postural sway in visual searching task compared with auditory digit span task. This postural instability can be due to the children's higher visual dependency while keeping the posture upright. Children with ASD have problems in integration of somatosensory, vestibular, and visual inputs as the requirements of postural stability [4,6]. Previous studies have explained how these children rely more on visual abilities in order to acquire accurate information needed for postural control as well as to deal with this sensory integrative dysfunction [7]. Thus, performing visual searching task decreases visual attentional resources that are allocated to postural control. This can result in higher postural instability in individuals with ASD. Kerr et al.,

Table 2
Postural sway parameters in different conditions in children with ASD compared with TD children.

	Auditory task		Visual task		Group		Condition		Condition by group	
	ASD	TD	ASD	TD	*F*	*p*	*F*	*p*	*F*	*p*
RMS_{AP}[a] (cm)	0.59 ± 0.29	0.35 ± 0.19	0.78 ± 0.77	0.36 ± 0.21	9.82	0.003	2.85	0.09	2.24	0.14
RMS_{ML} (cm)	0.80 ± 0.73	0.32 ± 0.18	0.99 ± 0.98	0.33 ± 0.25	11.97	0.001	4.6	0.03	3.33	0.07
RMS (cm)	1.03 ± 0.74	0.50 ± 0.22	1.29 ± 1.21	0.51 ± 0.29	11.75	0.001	5.88	0.01	4.45	0.04
MV_{AP}[b] (cm/s)	3.57 ± 1.08	3.16 ± 0.86	5.40 ± 5.00	3.12 ± 0.89	5.86	0.02	4.14	0.04	4.45	0.04
MV_{ML} (cm/s)	6.27 ± 4.69	4.76 ± 2.58	9.18 ± 8.46	4.37 ± 1.54	8.29	0.006	2.27	0.13	3.93	0.05
MV (cm/s)	7.88 ± 4.56	6.29 ± 2.67	11.71 ± 6.01	5.90 ± 1.93	10.17	0.003	3.95	0.05	5.94	0.01
SA[c] (cm^2/s)	36.39 ± 25.20	16.31 ± 9.70	53.84 ± 43.34	16.96 ± 11.12	21.77	<0.001	6.21	0.01	5.35	0.02

Note: ASD, autism spectrum disorders; TD, typically developing children; AP, anteroposterior; and ML, mediolateral.

[a] Root mean square.

[b] Mean velocity

[c] Sway area.

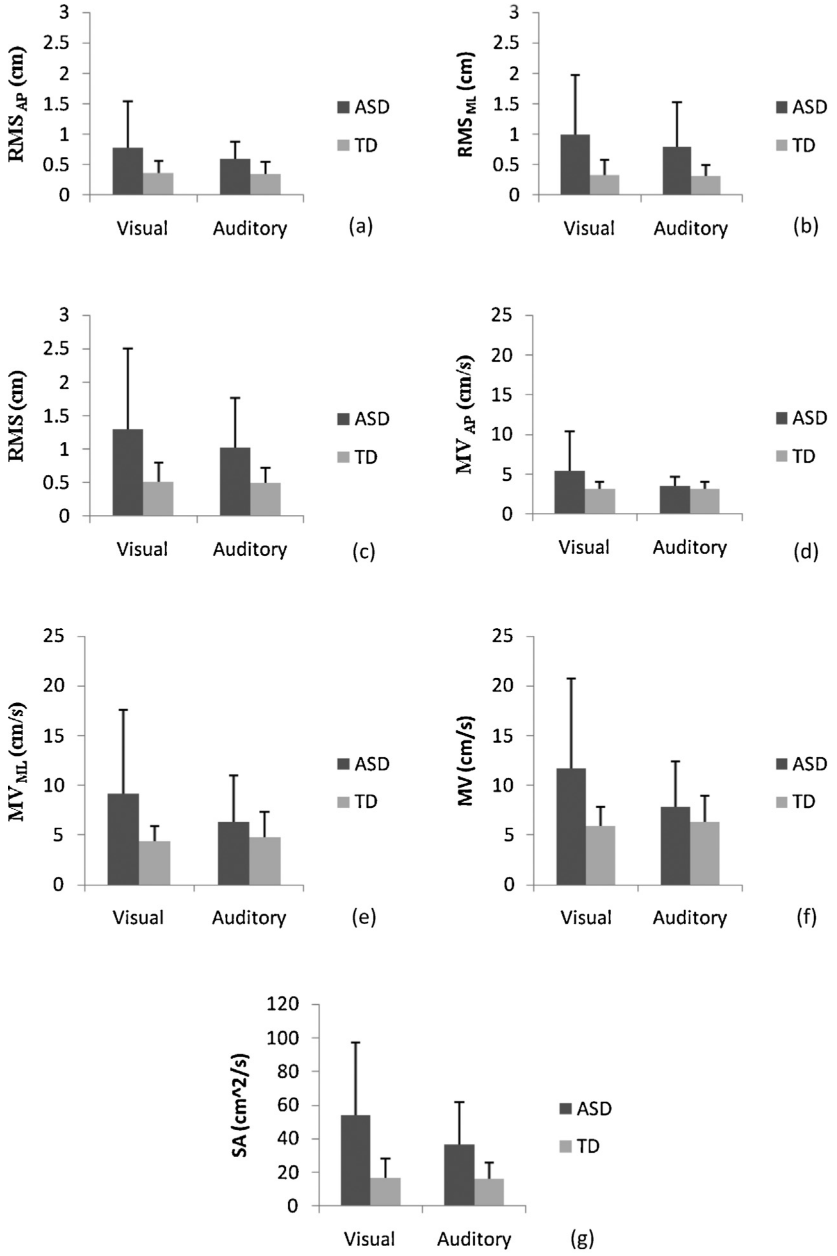

Fig. 1. Postural sway changes in visual and auditory task among ASD (autism spectrum disorder) and TD (typically developing) children. RMS, root mean square (a–c); MV, Mean velocity (d–f); SA, sway area (g); AP, Antero-posterior; and ML, medio-lateral.

further explained that visiouspatial task interferes more with postural control than verbal memory task [25]. They discussed that individuals may apply common visiouspatial information in processing of postural task as well as visul task. Therefore, postural task performance may adversely be affected during this combination. Consequently, one can hypothesize that children with ASD that have impairements in both spatial attention and shift attention may exhibit higher postural sway while performing a visual searching task [26].

Another possible explanation for higher instability during visual task compared with auditory task is due to patterns of eye movements. In line with previous studies, deliberate eye movements can affect postural behaviors and change the sway patterns [27,28]. Although in the auditory task participants fixed their eyes at the stationary visual marker, in the searching visual task, children were asked to search for the specific target that needs a continuous eye movement over the page. In other words in searching task, children had to switch from an object to another repeatedly. Consequently one can argue that autistic children with major impairments in shifting attention can show higher dual task interference and higher postural sway during visual against auditory task performance [11]. Previous studies support this hypothesis by showing that children with dyslexia exhibited higher levels of postural sway during text reading or performing Stroop tasks compared with executing eye fixation tasks [29]. However, some previous studies indicated an inconsistency, though the task performance is not clear in their methods [18]. In Chang et al.'s study, it seems that children were allowed to look over a plain picture but they were not forced to fix their eyes on a specific visual marker.

Our results indicate that using dual task paradigm with different sensory inputs has an important role in identifying postural control patterns in ASD. Some previous findings indicated no association between the types of sensory inputs and postural control changes during dual task assessment. In other words, they support the fact that during the postural control tests, secondary cognitive tasks (not counting the type) recruit general rather than specific processing mechanisms or attentional pools [10]. In contrast, Riley et al., suggested that each sensory input may influnce the postural control using a specific rather than general mechanism [14,25]. Although we could not directly examine the processes underlying each condition, significant distinction between postrual sway patterns when autistic children performing a visual task against auditory task can suggest that there are specific mechanisms, at least, besides general mechansims decreasing attentional resources during dual task assessment. However, there is still insufficient data and current findings must be interpreted with caution because the result was limited to children with ASD but not TD children. This area deserves further investigations with other clinical populations and other age groups of general populations.

5. Limitation and future direction

There are certain limitations for our study. First, the small sample size of ASD may have affected significant p values in postural sway differences and limit the generalizability of findings. Second, the visual and auditory tasks used in this study were not pure in a specific sensory modality and possibly did not have equal difficulty levels between children with ASD and their TD counterparts. Further studies with large sample sizes are recommended to consider cognitive tasks with different levels of difficulties and attentional demands. In addition, it is warranted to consider physiological responses (such as EMG, EEG, and skin conductance) to examine underlying mechanisms of postural control. To understand tremendous heterogeneity in ASD, it is further suggested to investigate postural control and its interference with sensory stimuli among subcategories of ASD (such as Asperger's and other autism spectrum).

6. Conclusion

This study demonstrates that postural control patterns during performing a visual or auditory task can discriminate children with ASD from their age matched TD children. Furthermore, findings support that each sensory stimulus may influence the postural control by a domain specific mechanism in children with ASD.

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Conflicts of interest statement

There are no declared conflicts of interest for any of the authors.

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