Visual Feedback Increases Postural Stability in Children with Autism Spectrum Disorder

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Highlights

- We examined postural control and ability to improve posture in children with ASD.
- ASD children were significantly more unstable than TD controls at baseline.
- They improved significantly when given visual feedback of their center of pressure.
- Posture training with visual feedback might improve general motor control in ASD.

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1. Introduction

The beneficial effect of training on the motor functioning of children with autism spectrum disorders (ASD) is well documented (Lang et al., 2010; Sowa & Meulenbroek, 2012). Still, the mechanisms that underlie this effect are rarely targeted by empirical research. In the current study, we wished to capture ability of children with ASD to use visual cues for improving their postural control, an important component of gross motor development.

1.1. Autism spectrum disorders and motor function

From the first clinical descriptions of ASD, poor motor skills have been commonly reported (Kanner, 1943). Empirical studies confirm that children with ASD experience both gross and fine motor delays and show atypical motor patterns (Ghaziuddin & Butler, 1998; Green et al., 2009; Ming, Brimacombe, & Wagner, 2007; Miyahara et al., 1997; Provost, Lopez, & Heimerl, 2007, for reviews see: Gidley-Larson & Mostofsky, 2006; Gowen & Hamilton, 2013). Motor function depends greatly on postural control, the fundamental and early-developing ability to maintain equilibrium by keeping or returning the center of body mass over its base of support (Horak, 1987). This was shown for instance in a sub-analysis conducted by Whyatt and Craig (2012) of the motor performance of children with ASD on the Movement Assessment Battery for Children (Henderson & Sugden, 1992), which assesses manual dexterity, ball skills and balance. They found that the motor skill deficits indicated by this test were specifically apparent in activities demanding core balance ability, such as static balance and catching a ball. A recent study (Mache & Todd, 2016) directly comparing motor skills and postural control in children with ASD has confirmed that a significant predictor of fundamental motor skill performance (locomotion and ball skills) in ASD is postural control.

1.2. Autism spectrum disorders and postural stability

Indeed, studies that have assessed postural stability in ASD by measuring balance time have generally found difficulties sustaining a posture for longer periods of time (Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Green et al., 2009; Jansiewicz et al., 2006; Noterdaeme, Mildenberger, Minow, & Amorosa, 2002; Papadopoulos et al., 2012, though see: Weimer, Schatz, Lincoln, Ballantyne, & Trauner, 2001 for diverging results). Research that used force plates to record the exact amount of movement made by participants when trying to hold a posture have also consistently reported increased sway in children with ASD during quiet stance (Fournier et al., 2010; Gepner & Mestre, 2002; Kohen-Raz, Volkmar, & Cohen, 1992; Memari et al., 2013; Minshew, Sung, Jones, & Furman, 2004, though see: Molloy, Dietrich, & Bhattacharya, 2003 for opposite results).

Balance is regulated through the afferent signals from the somatosensory, the vestibular and the visual systems (Peterka & Benolken, 1995). Experiments that manipulated afferent inputs show abnormal compensatory functioning between the three subsystems in ASD. For example, in Weimer et al.'s study (2001), while children and young adults with Asperger Syndrome (AS) balanced on one leg with eyes open for a similar amount of time as controls, they balanced for significantly less time when standing on one foot with eyes closed.

Similarly, Molloy et al. (2003) found that when their vision was occluded, children with ASD had significantly more difficulties in maintaining balance than controls, whether or not somatosensory input was also modified, which suggests an overreliance on visual cues. Two recent studies have further confirmed this visual dependency by showing that children with ASD show more postural sway than controls when their eyes are closed (Stins, Emck, de Vries, Doop, & Beek, 2015) or while performing a visual searching task as compared to sway during an auditory digit span task (Memari, Ghanouni, Shayestehfar, Ziaee, & Moshayedi, 2014).

Minshew et al. (2004) compared how individuals with ASD (children and adults) and controls compensate for disrupted visual, vestibular or somatosensory inputs and found the relative importance of the latter to be the greatest. In this study, the postural stability of individuals with ASD was significantly reduced compared to controls when somatosensory input was disrupted alone or in combination with the disruption of the visual input. The authors also revealed a specific developmental trajectory for postural stability in persons with ASD. Postural control did not begin to improve until the age of 12 years in children with ASD and never achieved adult levels, whereas in controls, it improved steadily from 5 to 15-20 years, before it plateaued.

An alternative hypothesis put forward by Gepner et al. (1995; 2002) is that atypical postural function in ASD does not derive from basic motor impairments but from a deficit in visual-motion integration, which can be captured in reduced reactivity to fast moving visual stimulation. They reported that children with ASD were posturally hyporeactive to visually perceived environmental motion in comparison with typically developing (TD) controls (Gepner et al., 1995). Greffou et al. (2012) further explored the question by assessing postural response in fully immersive dynamic virtual tunnels. Similarly to Gepner et al. (1995; 2002), they also found abnormal postural reactivity in participants with ASD, but only in the younger group (aged 12-15 years) and for specific oscillation frequencies.

Although the role of postural reactivity remains uncertain, the above studies underscore the relative importance of visual cues for maintaining balance in ASD.

1.3. The effect of IQ

Postural stability seems to be linked to IQ (Minshew et al., 2004) and level of functioning in ASD (Gepner & Mestre, 2002; Kohen-Raz et al., 1992; Memari et al., 2013). Children with ASD who have intellectual disability are more likely to show reduced postural stability even in static conditions with a stable floor and normal visual input (Kohen-Raz et al., 1992; Memari et al., 2013; Minshew et al., 2004). Cognitively able children with ASD on the other hand seem to catch up with TD children from the age of about 12 years, after which abnormal functioning has been found only for challenging conditions where afferent inputs were modified (Greffou et al., 2012; Minshew et al., 2004; Weimer et al., 2001). Only few studies, however, have explored postural skills in children with ASD below the age of 12, with some confirming prolonged delay until this age (Fournier et al., 2010; Memari et al., 2013; Minshew et al., 2004), but not others (Molloy et al., 2003; Price, Shiffrar, & Kerns, 2012). Inconsistent findings may be due to the variability of assessment methods and sway measures as well as to samples often covering a wide age range.

1.4. The present study

Our present study had two aims. First, we wished to disambiguate existing data on the postural skills of children with ASD below the age of 12 by measuring postural stability in children with ASD without intellectual disability aged 5-11 years. We hypothesized that examining a large sample and a close age range with precise posturography, we would find reduced baseline postural stability in this young population (Fournier et al., 2010; Memari et al., 2013; Minshew et al., 2004).

Secondly, we wished to explore the effect of visual feedback on postural performance. Our second hypothesis was that, given their strong reliance on visual cues when maintaining balance (Gepner et al., 1995; Gepner & Mestre, 2002; Greffou et al., 2012; Memari et al., 2014; Molloy et al., 2003), children with ASD would improve in their postural performance if provided with contingent visual feedback of the movements of their center of pressure (CoP).

2. Methodology

2.1. Participants

We recruited 18 children with ASD (14 boys) from two schools for children with ASD in Budapest, Hungary. Each child had completed the assessment procedure required for a formal diagnosis of ASD in order to enter the schools. During this procedure children were examined by a multidisciplinary team composed of a general practitioner, a clinical psychiatrist and an educational psychologist. They were diagnosed with autistic disorder according to DSM-IV-TR (American Psychiatric Association, 2000) criteria. The Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al., 2000) and the Autism Diagnostic Interview-Revised (ADI-R; Lord et al. 1994), were used to establish diagnoses. These were administered by the educational psychologist, who was qualified for using these diagnostic tools. The schools' professionals assessed the severity of the children's ASD symptoms with the Childhood Autism Rating Scale (CARS; Schopler, Reichler, & Renner, 1993) upon admission and each schoolyear. All the children with ASD participating in the study had CARS scores between 30 and 37 (mean 34,5 points) indicating mild to moderate autism (Mayes et al., 2012). We excluded children who had any genetic/medical conditions commonly comorbid with ASD (Fragile X-, Down- or Tourette syndrome, seizures, epilepsy), physical impairments or handicaps by screening the children's medical history. None of the children were under medication during the testing period.

Their ages ranged from 5 to 11 years (65 to 133 months, mean: 94 months). All the children had non-verbal IQs within the average range and average receptive language levels, as measured with Raven's Colored Progressive Matrices (R-CPM, Raven, 1993, Rózsa, 2006) and the Peabody Picture Vocabulary Test (PPVT-R, Dunn, 1997), respectively. Receptive language level was measured in order to ascertain that children with ASD would understand the task instructions. Parents were asked to fill the Movement Assessment Battery for Children – 2 Checklist (MABC –2 Checklist, Henderson, Sugden & Barnett, 2007), which focuses on how a child manages everyday situations in school or at home and indicates whether a child is likely to have gross motor abnormalities. According to this measure none of the children had gross motor impairments.

As the control group, we recruited 12 healthy age-matched TD children (8 boys) from a mainstream public school in Budapest, Hungary.

Their ages ranged from 7 to 9 years (86 to 112 months, mean: 97 months). Their non-verbal IQs, as measured with Raven's Colored Progressive Matrices (R-CPM, Raven, 1993, Rózsa, 2006) were found to be within the average range. TD children were also screened with the MABC –2 Checklist (Henderson, Sugden & Barnett, 2007), which indicated that none of them had gross motor impairments. We assumed that healthy, TD children attending a regular public school would understand the simple instructions of our task, their receptive vocabulary level was therefore not measured. Exclusion criteria were known genetic, mental or neurological disorders or physical impairments, which were screened with a further parent questionnaire. None of the parents reported the presence of any such conditions.

Written consent to recruit and test in the schools was first obtained from each school's principal. We distributed information letters briefly describing the study via the school to parents of children between 5 to 11 years of age. Tear-off forms were appended to the letter, allowing us to contact parents who were interested in the study in order to provide further information and to obtain their signed informed consent. The study was approved by the Medical Ethics committee of the University of Budapest.

Participants' descriptive statistics are reported in Table 1. The two groups of children with ASD and TD children were well matched on chronological age (t (28) = 0.43, p = .33). Regarding mental age, the TD group had significantly higher IQs (t (28) = 4.91, p < .0001). However, as all participants had IQs within the average range and were above clinical criteria for impaired IQ (with IQ scores above 70), the groups were retained. For more precise analyses, the group of children with ASD was split into two subgroups based on IQ; children with ASD - IQ>100 (n=10) and children with ASD - IQ 80-100 (n=8).

Please insert Table 1 about here.

2.2. Apparatus

Postural sway measurements were performed using the Virtual Human Interface platform© (Digital Elite/PanoCAST, Inc., Los Angeles, CA), which employs real-time graphics and imaging to provide various visual (or auditory) stimuli related to specific rehabilitative needs. The hardware consisted of a HP Probook laptop communicating via Bluetooth connectivity with a Nintendo Wii balance board (511 x 316 x 53.2 mm) that registered the actual location and movement of the CoP of the participants' body. The Wii balance board has been found to be a reliable and valid tool to measure balance in research and clinical settings (Clark et al., 2010). Data generated by the balance were processed by custom software named Cyber Care Clinic© (Digital Elite/PanoCAST, Inc., Los Angeles, CA), which transposed CoP movements to the laptop's 17-inch monitor (resolution of 42 pixels per cm). The child's CoP was represented by a blue rectangle (1.6cm x 1cm) that moved in conjunction with the movements of the child's CoP within a greater white circle. Figure 1 shows the visual feedback presented to children on the monitor.

Please insert Figure 1 about here.

2.3. Measurements

Cyber Care Clinic© software calculated two postural sway measures: (1) participants' Sway Area (SA), the area of the outer envelope created by the x-y plot of the movement pattern of the participants' CoP, and (2) Sway Length (SL), the total distance traversed by the CoP. Cyber Care Clinic© performed these calculations with consideration of the weight and the height of each participant. As CoP movements were transposed to a [-1,1] normalized space, measurements were relative, non-dimensional values with no units.

2.4. Procedure

The experiments took place within the schools in a quiet room that was familiar to the child (such as the school library). Experimenters were therefore not blind to children's group membership. One experimenter managed the software while the other communicated with the child. Both ensured that the child understood the task and stood correctly with arms next to his or her body, heels touching and eyes on the monitor. Throughout the session, verbal instructions were simple and standardized in order to minimize any confounding elements of language and comprehension.

During the tasks (except the Baseline Condition) the balance board was placed on the floor 0.8m from the table on which the computer was located. The monitor's center was at the eye-level of the child. Each session consisted of the following three phases, 60s long each.

1. Baseline Condition: the child was asked to stand still on the balance board during 60s, without performing any movement. The child could not see the monitor. In order to obtain steady state results, the first and last 5 seconds were removed from the data and only the remaining 50 seconds were analyzed.
2. Training: 'Move the blue box on the screen' game. The experimenter asked the child to stand on the balance board, this time facing the monitor. She then showed to the child a small blue square on the monitor and explained that he or she could move this 'blue box' by swaying his or her body. The blue square moved in conjunction with the movements of the child's CoP. The aim of this 60s familiarization period was to train children to use the apparatus and to ensure that they understood that the movement of their CoP was represented on the screen. Data recorded during familiarization was not analyzed.
3. Visual Feedback Condition: 'Keep the blue box still' game. The child remained on the balance board, was asked to stand comfortably and to keep as still as possible so that

the ‘blue box’ would not move. The trial lasted 60s, during which we recorded children’s postural performance. As in the Baseline Condition, only 50 seconds of the data were analyzed.

2.5. Statistical analysis

Analyses were conducted on the average of data recorded during each phase. Mean SA and SL across Conditions (Baseline vs. Visual Feedback) in children with ASD and TD children were compared. 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

Figure 2 shows examples for scatter plots generated by the postural performance of a child with ASD and a TD child in the Baseline and the Visual Feedback Conditions. A mixed-design ANOVA with Condition (Baseline or Visual Feedback) as within-subjects factor and Diagnosis (ASD or TD) as between-subjects factor revealed significant effects of Visual Feedback on both SA ($F(1, 28) = 9.48$, $p=.005$, $\eta_p^2= .253$) and SL ($F(1, 28) = 573$, $p< .0001$, $\eta_p^2= .953$). We found interactions between Condition and Diagnosis ($F(1, 28) = 4.51$, $p=.043$, $\eta_p^2= .139$ for SA and $F(1, 28) = 22.94$, $p< .0001$, $\eta_p^2= .45$ for SL), suggesting that contingent visual feedback of CoP had a greater effect on postural control in children with ASD than in TD children.

Figure 3 shows mean SA and SL of children with ASD and TD children as a function of Condition. Subsequent comparisons of means are presented below.

Please insert Figures 2 and 3 about here.

3.1. Baseline SA and SL

In the Baseline Condition postural stability was significantly lower in children with ASD than in TD children for both SA (t(28) = 3.13, p < .01) and SL (t(28) = 4.36, p < .0001) measures. Table 2 shows comparisons of mean baseline SA and SL for the two subgroups of children with ASD, determined by level of IQ. We found that SA was significantly greater in both the children with ASD - IQ>100 subgroup (n=10; t(20) = 3.08, p < .01) and the children with ASD – IQ 80-100 subgroup (n=8; t(18) = 4.08, p < .001) than in TD children. Similarly, baseline SL was significantly greater in both the children with ASD - IQ>100 subgroup (n=10; t(20) = 3.08, p < .01) and the children with ASD – IQ 80-100 subgroup (n=8; t(18) = 4.08, p < .001) than in controls. Our first hypothesis was thus confirmed, as baseline SA and SL were greater in children with ASD than in TD children, independently of IQ.

3.2. The effect of visual feedback on postural stability

Comparisons of mean SA and SL of children with ASD in the Baseline and the Visual Feedback Conditions revealed that postural stability increased when visual feedback was provided, as both SA (t(17) = 2.4, p < .05) and SL (t(17) = 3.31, p < .01) decreased significantly (see Figure 3). These results confirmed our second hypothesis; the postural performance of children with ASD improved when contingent visual feedback was provided of the movements of their CoP.

Although they improved remarkably, children with ASD still had a significantly greater SA (t(28) = 2.83, p < .01) and SL (t(28) = 2.83, p < .01) than TD children. In the TD group, no difference in SA or SL was found; their postural stability was comparable to baseline in the Visual Feedback Condition.

We again compared means for the two subgroups of children with ASD separately (see Table 2). Just like the greater group, children with ASD in the IQ 80-100 subgroup (n=8) improved significantly in their postural stability when provided visual feedback of the movement of their CoP (Z = -2.09, p = .037). However, even their improved SA remained significantly larger than that of TD children (t(18) = 2.02, p < .05). Children with ASD in the IQ>100 subgroup (n=10) also improved in their postural stability when provided visual feedback, but the difference between their SA in the Baseline and the Visual Feedback Conditions did not reach significance. Just as in the greater group though, their improved SA was still significantly larger than that of TD children ($t(20) = 3.95$, $p < .001$). These comparisons show that the effect of visual feedback was greater in the group of children with ASD with slightly lower IQ.

4. Discussion

Children with ASD often show atypical motor patterns (Gidley-Larson & Mostofsky, 2006; Gowen & Hamilton, 2013), which might in part be due to an immature postural control (Mache & Todd, 2016; Whyatt & Craig, 2012). Firstly, our findings confirm the presence of this deficit in childhood by showing that postural stability is reduced below 12 years of age in children with ASD, even during quiet stance (Fournier et al., 2010; Memari et al., 2013; Minshew et al., 2004). Secondly, we provide new insight into postural instability by showing that it can be improved in a specific, facilitating environment, which in our case consisted of providing contingent visual feedback of the child’s CoP movements. Thirdly, we found that postural instability was linked to IQ. Although children with ASD in our study were all above clinical criteria for impaired IQ (with IQ scores above 70), similarly to earlier data (Minshew et al., 2004), we observed that children with ASD who had an IQ between 80 and 100 produced greater SAs than children with ASD with an IQ above 100. Interestingly, although both groups improved, children in the lower IQ group benefited more from visual feedback and reached greater stability than children in the higher IQ group.

It has been proposed that the common neural substrate linking postural and motor deficits in ASD could be the cerebellum (Nayate, Bradshaw, & Rinehart, 2005), which optimizes motor performance in a given context and supports initial motor skill learning. Structural and functional abnormalities of the cerebellum in ASD have been reported by numerous studies (for a review, see: D'Mello & Stoodley, 2015), supporting the cerebellar hypothesis of these disorders (e.g.: Courchesne, Yeung-Courchesne, Press, Hesselink, & Jernigan, 1988; see Fatemi et al., 2012 for a review). Still, as multiple regions of the brain show abnormalities in this complex syndrome, further studies are required to clarify to what extent ASD can be considered a disorder of the cerebellum.

The first limitation of our study is the modest sample size, which allowed analyses on the effect of IQ only on small subgroups of children with ASD, all above the clinical criteria of intellectual disability. Thus, the beneficial effect of visual feedback (and its selectivity) needs to be confirmed by investigating the effect of postural training in children with ASD who have intellectual disability. Also, possible comorbid symptoms of ADHD could not be ruled out within this sample, as the DSM-IV-TR (APA, 2000) precludes a diagnosis of ADHD if ASD is present.

Secondly, in the absence of comparison data from children with other developmental disorders, the individual contributions ASD and developmental disorder per se remain unclear at present. Deficits in postural control have in fact been associated with other developmental disorders such as attention deficit hyperactivity disorder, Tourette syndrome, developmental coordination disorder, cerebral palsy, and hearing loss (for a review, see; Memari, Ghanouni, Shayestehfar, & Ghaheri, 2014).

Thirdly, we would like to note that the MABC –2 Checklist (Henderson, Sugden & Barnett, 2007) we used to assess gross motor functioning in our samples is a relatively coarse-grained measure that may not detect dysfunctions in the sub-clinical domain. With this tool we only wished to exclude gross motor problems that could have interfered with balance performance, it did not allow for us to explore correlation between motor skills and postural control. A recent study however (Mache & Todd, 2016) that used more precise measures of fundamental motor skill performance has confirmed correlation between the two, showing that a significant predictor of fundamental motor skill performance (locomotion and ball skills) in ASD is postural control.

We conclude that in a specialized setting adapted to their needs, in our case their preference for relying on real-time visual cues, children with ASD can learn to correct their posture. In practice we suggest that using similar postural or motor tasks with a Wii balance board for instance could well complement early interventions for CWA. Lang and colleagues (2010) conducted a systematic review of studies focusing on the effects of physical exercise in individuals with ASD and found that following motor interventions stereotypy, aggression and off-task behaviors decrease. Similarly, balance training early in development may help not only to improve motor abilities, but also to alleviate ASD symptoms.

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Visual Feedback Increases Postural Stability in Children with Autism Spectrum Disorder

Figures

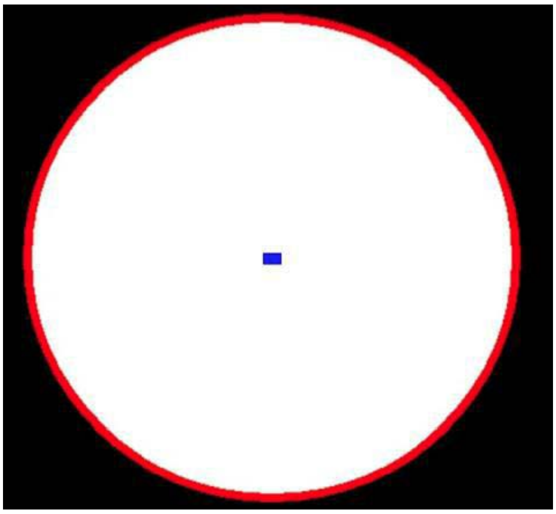


Figure 1 Visual feedback presented to children on the computer monitor during the ‘Move the blue box’ familiarization game and the ‘Keep the blue box still’ postural task. The blue square moved contingently with the movements of children’s center of pressure.

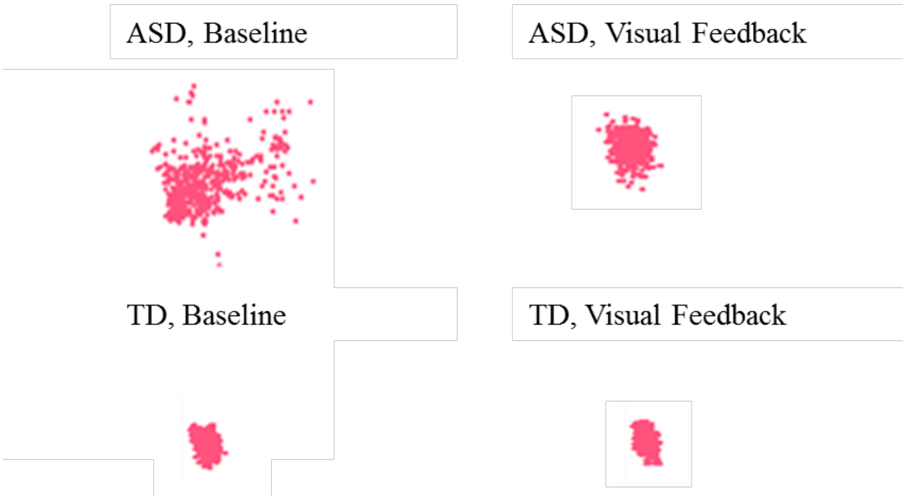


Figure 2 Scatter plots showing the movement of two 8-year-old subjects’ center of pressure (CoP). The two plots on the top belong to a child with autism spectrum disorder (ASD), whereas the two on the bottom belong to a typically developing (TD) child. The plots on the left show the pattern of CoP movement when the child was standing quietly with eyes open on a firm surface in the Baseline Condition. Those on the right show pattern of sway in the Visual Feedback Condition. We can see that the sway area (SA) of the child with ASD is larger in the Baseline Condition than the SA of the TD child. This area shrinks close to normal when visual feedback is provided.

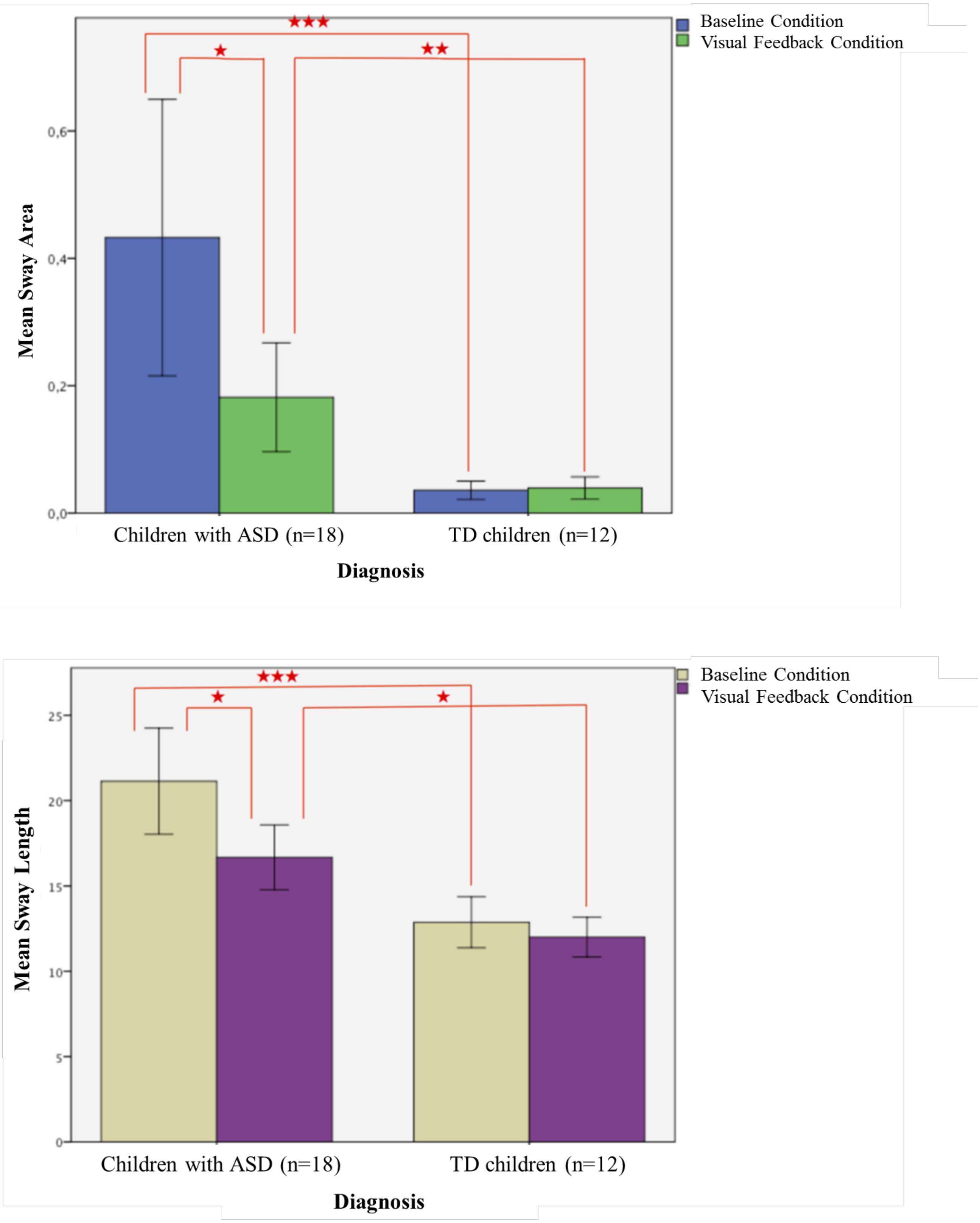
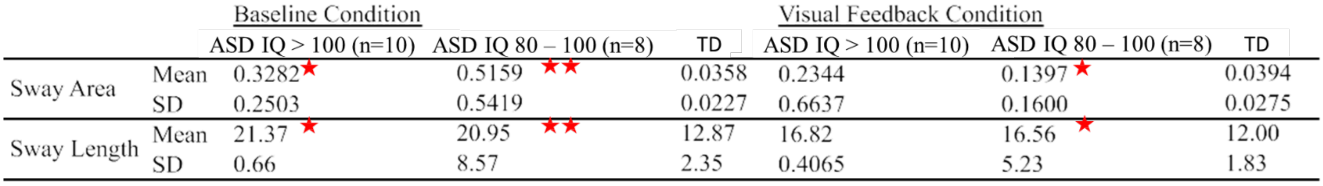


Figure 3 Children’s postural sway measured in Mean Sway Area and Sway Length as a function of Diagnosis (children with autism spectrum disorder (ASD) vs. typically developing (TD) children) and Condition (Baseline vs. Visual Feedback). A single asterisk indicates significance at $p < .05$, two asterisks indicate $p < .01$ and three indicate $p < .001$.

Tables

	ASD (n=18)		TD (n=12)		
	M	Std.dev.	M	Std.dev.	p
Age (months)	94	18.5	96	9.6	n.s.
Non-verbal IQ (R-CPM)	98	17.9	124	7.3	< .0001
Receptive language (PPVT-R)	81	20	NA	NA	NA
ASD symptom severity (CARS)	35	2.23	NA	NA	NA

Table 1 Descriptive statistics of the two groups of participants: children with autism spectrum disorder (ASD) and typically developing (TD) children. Non-verbal IQ was measured with Raven’s Colored Progressive Matrices (R-CPM) in both groups. For children with ASD receptive language level was assessed with the Peabody Picture Vocabulary Test (PPVT-R) and symptom severity with the Childhood Autism Rating Scale (CARS). CARS scores indicate mild to moderate autism in our sample of children with ASD.



		Baseline Condition			Visual Feedback Condition		
		ASD IQ > 100 (n=10)	ASD IQ 80 – 100 (n=8)	TD	ASD IQ > 100 (n=10)	ASD IQ 80 – 100 (n=8)	TD
Sway Area	Mean	0.3282★	0.5159 ★★	0.0358	0.2344	0.1397 ★	0.0394
	SD	0.2503	0.5419	0.0227	0.6637	0.1600	0.0275
Sway Length	Mean	21.37 ★	20.95 ★★	12.87	16.82	16.56 ★	12.00
	SD	0.66	8.57	2.35	0.4065	5.23	1.83

Table 2 Postural sway parameters as a function of Condition in two subgroups of children with autism spectrum disorder (ASD) determined by level of IQ, compared with typically developing (TD) children. Asterisks in the Baseline Condition column indicate significant differences between means as compared to the TD group. Asterisks in the Visual Feedback Condition column indicate significant differences between means as compared to the Baseline Condition. A single asterisk indicates significance at $p < .05$, two asterisks indicate $p < .01$.