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Movement Perception and Movement Production in Asperger's Syndrome

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Abstract

To determine whether motor difficulties documented in Asperger's Syndrome (AS) are related to compromised visual abilities, this study examined perception and movement in response to dynamic visual environments. Fourteen males with AS and 16 controls aged 7 to 23 completed measures of motor skills, postural response to optic flow, and visual sensitivity to static form and coherent motion in random dot kinematograms and point-light walkers. No group differences were found in sensitivity to static form or coherent motion. However, significant group differences were found in visual sensitivity to human movement and postural responsivity to optic flow, which both correlated with motor skills. This may suggest difficulties in perception and production of movement and dysfunctional perceptual-motor linkages in AS.

Keywords: Autism spectrum disorder (ASD), Asperger's Syndrome (AS), motor skills, motion perception, biological motion.

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Movement Perception and Movement Production in Asperger's Syndrome

Previously researchers have documented movement impairments in individuals with Asperger's Syndrome (AS) and autism (e.g., Freitag, Kleser, Schneider, & von Gontard, 2007; Ghaziuddin & Butler, 1998; Green et al., 2002; Green et al., 2009; Jansiewicz et al., 2006; Manjiviona & Prior, 1995; Miyahara et al., 1997; Smith, 2000). Motor behavior is not an isolated process but instead depends upon input from the visual, proprioceptive, and vestibular systems. Children with Autism Spectrum Disorder (ASD) rely heavily upon visual cues for balance in static environments (Molloy, Dietrich, & Bhattacharya, 2003). The purpose of the present study was to determine whether visual sensitivity to dynamic cues was related to motor abilities in youth with AS.

The accurate and timely visual analysis of movement is fundamentally important for the production and control of motor activity. Several studies have been published suggesting that children with ASD are compromised in their sensitivity to coherent visual motion (Davis, et al., 2006; Milne et al., 2002; Pellicano et al., 2005; Spencer et al., 2000; Spencer & O'Brien, 2006; Tsermentseli et al., 2008). Other researchers have concluded that, to the contrary, children with ASD do not differ from typicals in their visual motion sensitivity (e.g., Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006; De Jonge et al., 2007). This variability in findings may be due to a relationship between individual differences in the visual perception of movement and differences in motor ability (Milne et al., 2006), which would be in keeping with other evidence of perception-action coupling such as, for example, enhanced visual sensitivity to one's own actions (e.g., Loula, Prasad, Harper, & Shiffrar, 2005).

Optic flow is the pattern of dynamic visual information that is projected onto the retina whenever individuals move through their environment (Gibson, 1950). Because specific patterns

of motor activity produce specific patterns of optic flow, the visual perception of large field optic flow normally triggers postural adjustments. When viewing large field optic flow displays, children with autism exhibit atypically small postural responses while the postural adjustments of children with AS are slightly larger than those in typically developing people (Gepner & Mestre, 2002). Atypical postural reactivity to optic flow by observers with autism and AS may reflect compromises in the coupling between the visual and motor system (Gepner et al., 1995; Gepner & Mestre, 2002). A related possibility is that observers with autism and AS demonstrate atypical motor responses because their motor systems receive atypical input from the visual system.

When people move, they do so relative to the surfaces in their environment. The above studies investigated visual sensitivity to surface motion in random dot kinematograms. People also move relative to other people. Neurophysiological (Herrington et al., 2007) and behavioural (Blake et al., 2003; Kaiser, Delmolino, & Shiffrar, submitted) evidence indicates that young observers with autism and AS are compromised in their visual sensitivity to human movement. These studies used point-light stimuli that are constructed by placing markers, or point-lights, on the major joints of moving people and filming their actions so that only the point-lights can be seen (Johansson, 1973). While observers with autism and AS can identify human motion in point-light displays, they demonstrate relative decrements in their visual sensitivity to human motion (Moore, Hobson, & Lee, 1997; Hubert et al., 2007). Since movement production depends upon visual motion perception, the above results raise the possibility that deficits in motor behavior reflect, at least in part, compromised input from needed visual processes.

The goal of the current study was to determine how children with AS perceive and respond to dynamic aspects of their visual environments and determine if their dynamic visual perception is related to their motor ability. Different perceptual and motor skills were assessed.

First, motor tests from a standardized battery were administered. Then, visual sensitivity to static patterns was assessed as a non-dynamic control condition. Visual sensitivity to dot-defined surfaces and people in motion and postural responses to optic flow were then measured. To the extent that motor clumsiness in AS reflects compromised processing of dynamic visual information, visual sensitivity to motion, but not static form, should correlate with motor skills.

Method

Participants

The AS group consisted of 14 youths recruited through a child and youth health centre. The control group consisted of 16 individuals recruited through advertisements in local newspapers. All participants were male. Exclusionary criteria included clinically significant language impairment, a Full-Scale IQ under 70, and significant neurological disorders or physical anomalies that interfere with motor behavior. The ages of the AS group (mean = 14.14 years, SD = 4.80 years, range = 7.75 to 23.00 years) and the control group (mean = 14.08 years, SD = 4.61 years, range = 7.42 to 23.67 years) did not significantly differ, $t(28) = .03$, $p > 0.5$. The University of Victoria Human Research Ethics Committee granted ethical approval for this study. Informed consent was sought from parents whenever a participant was less than 18 years old.

Diagnoses of AS were made independently of this study by a multidisciplinary team. Within this study, symptom patterns and severity were assessed with three parent-completed symptom checklists: the Gilliam Asperger Disorder Scale (GADS, Gilliam, 2001), the Asperger Syndrome (and high functioning autism) Diagnostic Interview (ASDI, Gillberg, Gillberg, Råstam, & Wentz, 2001), and the high-functioning Autism Spectrum Screening Questionnaire (ASSQ, Ehlers, Gillberg, & Wing, 1999).

Symptom frequencies between the AS and control groups were clearly separated (Table 1). For seven of the eight measures, score distributions did not overlap. All measures of symptomatology differed significantly ($p < .001$) across the two groups. In terms of diagnostic cut-offs, the GADS showed clear separation with only one of the participants with AS in the "Borderline" range and the rest in the "High/Probable" range. All of the controls had GADS scores falling in the "Low/Not Probable" range. On the ASSQ, only one participant with AS had a score below the cut-off, and no controls had a score approaching the cut-off. On the ASDI, only four participants with AS had scores below the cut-off.

All participants were also given the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999). The verbal abilities (Vocabulary) of the AS (reported as *T*-scores, M = 60.14, SD = 9.44, range 43-73) and control (M = 57.81, SD = 9.29, range 40-70) groups did not significantly differ, $t(28) = 0.68$, $p > .50$. Likewise, scores on the Matrices subtest, a measure of nonverbal intellectual ability, did not significantly differ across the AS (M = 57.14, SD = 7.43, range 42-65) and control (M = 52.63, SD = 9.29, range 38-68) groups, $t(28) = 1.46$, $p > 0.10$.

Materials and Procedure

After providing informed consent, participants completed WASI testing. Following this, all participants completed the tasks below in the order listed. All participants were tested individually in a university laboratory, and completed all tasks using the same equipment.

Dean-Woodcock Neuropsychological Battery.

The Dean-Woodcock Neuropsychological Battery (Dean & Woodcock, 2003, see also Woodward et al., 2002) includes a number of classical clinical motor tests, similar to those used in previous research on motor skills in AS. For the purposes of this study, these motor tests were organized into 'Gross' and 'Fine' motor designations. The Gross Motor tests included

assessments of locomotion, balance, posture, and gross motor movement including: Gait and Station, a Romberg task, and Coordination (alternating between touching the front and back of the hand to the thigh), Mime Movements (a test of ideomotor apraxia), and Grip Strength. The Fine Motor tests assessed more complex motor skills and included Construction (two figures), Finger Tapping (dominant and non-dominant hands) and Expressive Speech tasks. None of the tasks had significant language requirements, and perception of motion is not involved in many of the tasks. The Dean-Woodcock provides norm referenced W-difference scores (a transformation of a Rasch logit scale) that index subjects' proficiency in comparison to others their age, and a 'Level of Impairment' scale with five categories ranging from 'Within Normal Limits' to 'Severely Impaired'.

Visual Motion Perception.

Visual sensitivity to motion was assessed with motion coherence thresholds obtained with a random dot kinematogram. Participants viewed two adjacent patches of moving dots shown against an otherwise homogeneous, black background (Figure 1B). Each patch was rectangular in shape and contained 300 white, high contrast dots. In one patch, all of the dots moved in random directions. In the other patch, some of the dots moved randomly while a varying percentage of dots oscillated synchronously left and right. Participants indicated with a button press on a computer keyboard which patch contained the coherently oscillating subset of dots. Display coherence is defined by the ratio of synchronously moving to randomly moving dots. Each dot had a 200 ms lifetime so that participants could not track any individual dot. Motion coherence thresholds were assessed by the smallest proportion of synchronously oscillating dots needed for an observer to detect the presence of coherent motion. Displays were initially set so that 75% of the dots in one of the patches moved coherently because all

participants could detect this level of motion coherence. From that point, stimulus coherence on any trial was set according to a one up, one down adaptive staircase procedure. There were four separate trial runs, each determining a different threshold for each participant, and the average across all four runs was subsequently analyzed. Additional details of this task are described in Milne et al. (2006) and in Hansen et al. (2001).

Static Form Perception.

The stimuli in the static form perception task consisted of two rectangular patches each containing static line segments (Figure 1A). In one of the patches, all of the line segments had random orientations. In the other patch, some variable proportion of the line segments had orientations that resulted in the formation of a large circle while the remaining line segments had random orientations. The line segments were white, and high contrast relative to the homogeneous black background. As before, an adaptive staircase procedure set the proportion of coherently oriented line segments on each trial. Participants reported with a button press whether the left or right rectangular patch contained the line-segment defined circle. Stimuli were presented until participant response. Additional details of this task are available in Hansen et al. (2001) and Milne et al. (2006).

Biological Motion Perception.

The stimuli consisted of 5-second movies of point light displays of human gait created from the motion capture data obtained with a 3-D VICON system. Motion capture data were obtained from volunteers with typical and atypical gaits who walked along a straight path approximately 4 meters in length. Each point-light display depicted lateral views of the lower half of each walker's body with 6 dots representing the hips, knees, and ankles (Figure 1C).

In total, there were 55 point-light movies; 28 depicting typical gaits and 27 depicting gaits with limps. Of these, half of the typical (14) and atypical (13) gaits were rendered incoherent by replacing one leg with the corresponding leg from a different walker. These incoherent "gait chimeras" depicted impossible movements since one hip always moved faster than the other.

On each trial, participants viewed one of the 55 possible point-light walkers and made two different perceptual assessments. All participants viewed the 55 point-light walkers presented sequentially in the same order. First, they reported if that point-light walker depicted the coherent gait of one person or the incoherent leg movements from two different walkers. Second, participants reported whether that same point-light movie depicted a typical gait or a limp. Participants recorded their perceptual decisions by clicking a mouse within a dialogue box that appeared immediately below the point-light walker. Each point-light walker was repeatedly displayed until the participant made a response.

Postural Stability During the Observation of Virtual Optic Flow.

In this task, participants stood on an AMTI AccuSway force plate (Advanced Mechanical Technology, Inc., Watertown, MA) while wearing a 5DT head mounted display (HMD) depicting a scene in virtual reality (VR). Each participant viewed two different VR scenes (rendered with C++ Open GL). The static scene depicted the stationary image of a computer desktop. The dynamic scene depicted a narrow school hallway with a door at the end and simulated the optic flow that would result from the observer walking slowly down this hallway (Figure 1D). The static scene was always presented first. Each scene was presented for 35 seconds. In the dynamic scene, the scene was static during the first five seconds and then the optic flow abruptly started to simulate the onset of walking down the hallway.

Participants were asked to stand still on the force plate for the duration of each trial. The dependent variable was each participant's shifts in the centre of pressure on the force plate, including the range of motion along the anterior-posterior and lateral axes, while viewing each scene. This task, then, is a modification of the Romberg test, which is a portion of neurological examinations looking at ataxia and unsteadiness associated with cerebellar or vestibular dysfunction. Although the purpose is to stand still, postural stability requires a variety of motor adjustments based on a variety of sensory inputs.

Results

Static Form and Motion Perception

In the static form perception task, thresholds of the percentage of aligned line segments needed for the detection of the circular target were calculated. Observers with AS (mean = 18.56%) and control observers (mean = 17.09%) had mean thresholds for the detection of static form that did not significantly differ (t (28) = 1.10, $p > .05$). When participants tried to identify the coherent motion in random dot kinematograms, the percentage of dots that observers needed to detect coherent motion did not differ across the AS (mean = 10.42) and control (mean = 9.64) groups (t (28) = 0.66, $p > .05$). Threshold values in this experiment fell within the range previously reported for observers with ASD (Milne et al., 2002).

Biological Motion Perception

Participants made two judgments of each point-light walker display: correctly judging whether each point-light walker depicted a coherent (hit) or incoherent (correct rejection) gait, and correctly judging whether each walker depicted a normal gait (hit) or a limp (correct rejection). When these four hit and correct rejection scores were summed, the control group (mean = 81.93, SD = 8.00) responded correctly significantly more frequently than participants

with AS (mean = 71.29, SD = 10.23), $t(27) = -3.13$, $p < .005$, Cohen's d = 1.21. Visual sensitivity to human motion was also assessed with d-prime measures calculated by subtracting the normalized rate of false alarms from the normalized rate of hits for each participant with each perceptual judgment (Macmillan & Creelman, 1991). When they judged whether each walker depicted a coherent or incoherent gait, participants with AS (mean d-prime = 1.57, SD = .96) performed more poorly than participants in the control group (mean = 2.28, SD = .73), t(27) = -2.27, $p < .05$, Cohen's d = 0.88. Overall, performance was much poorer when participants judged whether each point-light walker depicted a normal gait or a limp. Despite near chance levels of performance, participants in the AS group (mean = .26, SD = .58) still tended to exhibit lower detection sensitivity than observers in the control group (mean = .62, SD = .51), t(27) = -1.76, $p < .10$, with a medium effect size (Cohen's d = 0.69).

Postural Stability During the Observation of Virtual Optic Flow

Postural stability was measured using the ranges of motion in the anterior/posterior (Y) and lateral (X) axes. When participants viewed the static scene, no significant differences in postural stability were found across the two groups (all *p*s > 0.10). However, when participants viewed the dynamic scene, participants in the AS group showed significantly more postural sway along the anterior/posterior (Y) axis (mean = 4.26 cm, SD = 2.02 cm) than participants in the control group (mean = 2.90 cm, SD = 1.18 cm), $t(27) = 2.22$, $p < .05$, Cohen's d = 0.87. The two groups did not differ significantly in their postural sway along the lateral axis (AS mean = 4.30 cm, SD = 4.22 cm; Control mean = 2.54 cm, SD = .92 ; $p > 0.10$). The standard deviations of these same variables reflected the same pattern. That is, participants in the AS group showed significantly more variability than the control group in their postural sway along the anterior/posterior axis (AS mean = .84 cm, SD = .34 cm; Control mean = .54 cm, SD = .25; *t*

(27) = 2.74, $p < .05$), but not the lateral axis (AS mean = .68 cm, SD = .46 cm; Control mean = .51 cm, SD = .21; $p > 0.10$), in the absence of group differences in standing still without optic flow.

Motor Measurements

In keeping with previous research, participants in the AS group scored significantly lower than control participants on the Fine and Gross Motor composites from the Dean-Woodcock (Table 2). Interestingly, analysis of the number of participants who had more than one task in which they scored in the mild or greater impairment range revealed a somewhat different picture, in that AS and control groups did not differ in the number of participants who had this level of impairment on fine motor tasks, but did differ significantly on gross motor tasks (Table 3).

The primary goal of this work was to determine whether there is a relationship between the motor difficulties that have consistently been associated with ASD and visual sensitivity to dynamic information. Therefore, correlations were computed with the fine and gross motor composites scores and performance on the visual tasks described above. Correlations of each of these variables with the Fine and Gross Motor composite scores, and the total score from the Dean-Woodcock are noted in Table 4. Better motor performance on the Dean-Woodcock was associated with increased sensitivity in the Motion Perception task, better performance in the Biological Motion task, and better postural stability while viewing virtual optic flow. Static form coherence threshold was correlated with gross motor skills, but not fine motor scores. Correlations between motor skills were more robust with biological motion perception and postural stability than with motion perception and especially static form perception. In fact, using a stepwise regression procedure to predict the total Dean-Woodcock motor score, only two variables (postural stability and biological motion) were included in the stepwise procedure

accounting for 52% of the variance (R^2 = .52, $F(1,26) = 14.15$, $p < .001$). Postural stability accounted for 42.8% of the variance with biological motion perception adding another 9.3%. Excluded from the stepwise procedure were static form perception and motion perception, as neither added significantly to the model.

However, given that group differences (AS or control) mediate motor skills, biological motion perception, and postural sway, separate correlations were calculated that controlled for the variance associated with the diagnostic group; these partial correlations are included in Table 5. As can be seen, better motor skills were still associated with less postural sway in the virtual environment, and greater sensitivity to biological motion, even after controlling for diagnosis.

Discussion

The goal of this work was to determine whether motor difficulties in AS might be related to perceptual deficits in visual sensitivity to dynamic information. A group of individuals with AS and a control group equivalent in age and IQ performed a series of tasks measuring visual and motor skills. Participants with AS did not differ significantly from control participants in the performance of static form or coherent motion detection. They did differ from controls, however, in their visual sensitivity to point-light walkers and postural reactivity to optic flow. Importantly, motor skills were more closely associated with visual perception of biological motion and postural reactivity to optic flow in a virtual reality environment than to visual sensitivity to static forms or motion that was not biologically relevant.

At present, there is significant debate as to whether observers with ASD differ from typicals in their visual sensitivity to coherent motion in random dot kinematograms and point-light displays of human motion (Kaiser & Shiffrar, 2009 in press). The current results are consistent with the hypothesis that observers on the autism spectrum are compromised in their

visual sensitivity to human motion and moving environments, but not necessarily motion in general. Milne and her colleagues (2006) reported that visual sensitivity to coherent motion in random dot kinematograms correlates with motor skills, which is supported by this study. However, visual sensitivity to random dot kinematograms is not related to motor skills as much as visual sensitivity to biologically relevant motion (e.g., motion produced through human movements, and optic flow that simulates the visual motion experienced when making human movements). Since previous studies of sensitivity to random dot kinematograms in AS samples have not matched participants on motor skills, differences across studies might reflect differences in motor skills within experimental groups. The current results are consistent with previous evidence of perception-action coupling such as, for example, enhanced visual sensitivity to one's own actions (e.g., Loula, Prasad, Harper, & Shiffrar, 2005). Of course, the current results are mute to the question of directionality, i.e., whether motor skills moderate visual motion perception, or whether visual motion perception moderates motor skills in AS. Nonetheless, the current results do indicate that motor skill assessments should be considered when addressing group differences in visual motion sensitivity.

Interestingly, performance on the biological motion task correlated with fine and gross motor skills. This is consistent with a recent imaging study of adolescent observers with ASD that identified significant correlations between gross motor abilities and neural activity in areas associated with the perception of point-light walkers (Freitag et al., 2008).

There are several limitations to the present study. First, the sample size was limited to 14 individuals with AS and 16 controls. It would be important to replicate this study with a larger sample. Such an expansion could allow for the study of developmental factors. The current sample spanned a large age range of 7 to 23 years, through which there is considerable brain

system development. In the current study, participants were closely matched on the basis of age to minimize its impact on group differences. However, it is possible that the results do not adequately reflect qualitative changes seen throughout development.

Second, differentiation of AS and autism is a contentious issue (e.g., Toth & King, 2008; Witwer & Lecavalier, 2008). Originally, clumsiness was considered to be an important factor in diagnoses of AS (e.g., Gillberg & Gillberg, 1989; World Health Organization, 1992). However, increasing evidence indicates that clumsiness does not differentiate AS from high functioning autism (e.g., Manjiviona & Prior, 1995; Ghaziuddin & Butler, 1998; Jansiewicz et al., 2006). Past work has demonstrated that it is important to control for IQ when comparing motor ability across groups (e.g., Green et al., 2009) as it was in the present study. It remains to be determined whether the current findings are specific to individuals with AS or generalize to people with autism.

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Table 1.

Symptom severity across diagnostic inventories by group.

	Asperger Group (N = 14)			Control Group (N = 16)		
	N	Mean (SD)	Range	N	Mean (SD)	Range
GADS	14			11		
Social Interaction		10.64 (2.47)	6-13		1.18 (0.60)*	1-3†
Restricted Behavior		10.50 (2.47)	7-14		1.45 (1.04) *	1-4†
Cognitive Patterns		10.50 (2.77)	5-14		2.64 (2.01)*	1-6
Pragmatic Skills		10.64 (2.73)	5-15		1.36 (0.67)*	1-3†
Asperger's Quotient		104.0 (14.01)	77-127		44.36 (5.10)*	40-57†
ASDI	13			11		
Total Score		13.69 (3.42)	7-19		0.36 (0.67)*	0-2†
Criteria		5.08 (1.04)	3-6		0.09 (0.31)*	0-1†
ASSQ	14	30.21 (6.12)	18-42	11	2.72 (2.37)*	0-8†

* $p < .001$

† Non-overlapping ranges

Table 2.

Means and Standard Deviations for W-Diff Scores of Gross and Fine Motor Composites.

Task	Group	N	Mean	SD	t-Score
Fine Motor Composite					
	AS	14	-4.25	5.24	-3.25*
	Control	16	1.02	3.61	
Gross Motor Composite					
	AS	14	-8.24	5.43	-4.32**
	Control	16	1.00	6.18	

* $p < .005$
** $p < .0001$

Table 3.

Number of Participants with More Than One Motor Task with Mild or Greater Impairment.

Task	Group	One or No Task with Impaired Score	More than One Task with Impaired Score	Total
Fine Motor Composite				
	AS	10	4	14
	Control	14	2	16
	Total	24	6	30
Gross Motor Composite**				
	AS	3	11	14
	Control	13	3	16
	Total	16	14	30

** Pearson Chi-square $p < .01$

Table 4.

Correlation of Visual Perceptual Tasks and the Dean-Woodcock Composites.

Perceptual Task	Bivariate Correlation		
	Fine	Gross	Total
Static Form Threshold	-.36	-.38*	-.42*
Motion Threshold	-.48**	-.42*	-.49**
Biological Motion	.56**	.56**	.63***
Postural Sway	-.58***	-.59***	-.65***

*** Correlation is significant at the 0.001 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 5.

Correlation of Visual Perceptual Tasks and the Dean-Woodcock Composites After the Variance Accounted for by Diagnosis was Removed.

Perceptual Task	Partial Correlation		
	Fine	Gross	Total
Biological Motion	.39*	.36	.44*
Postural Sway	-.47*	-.48**	-.57**

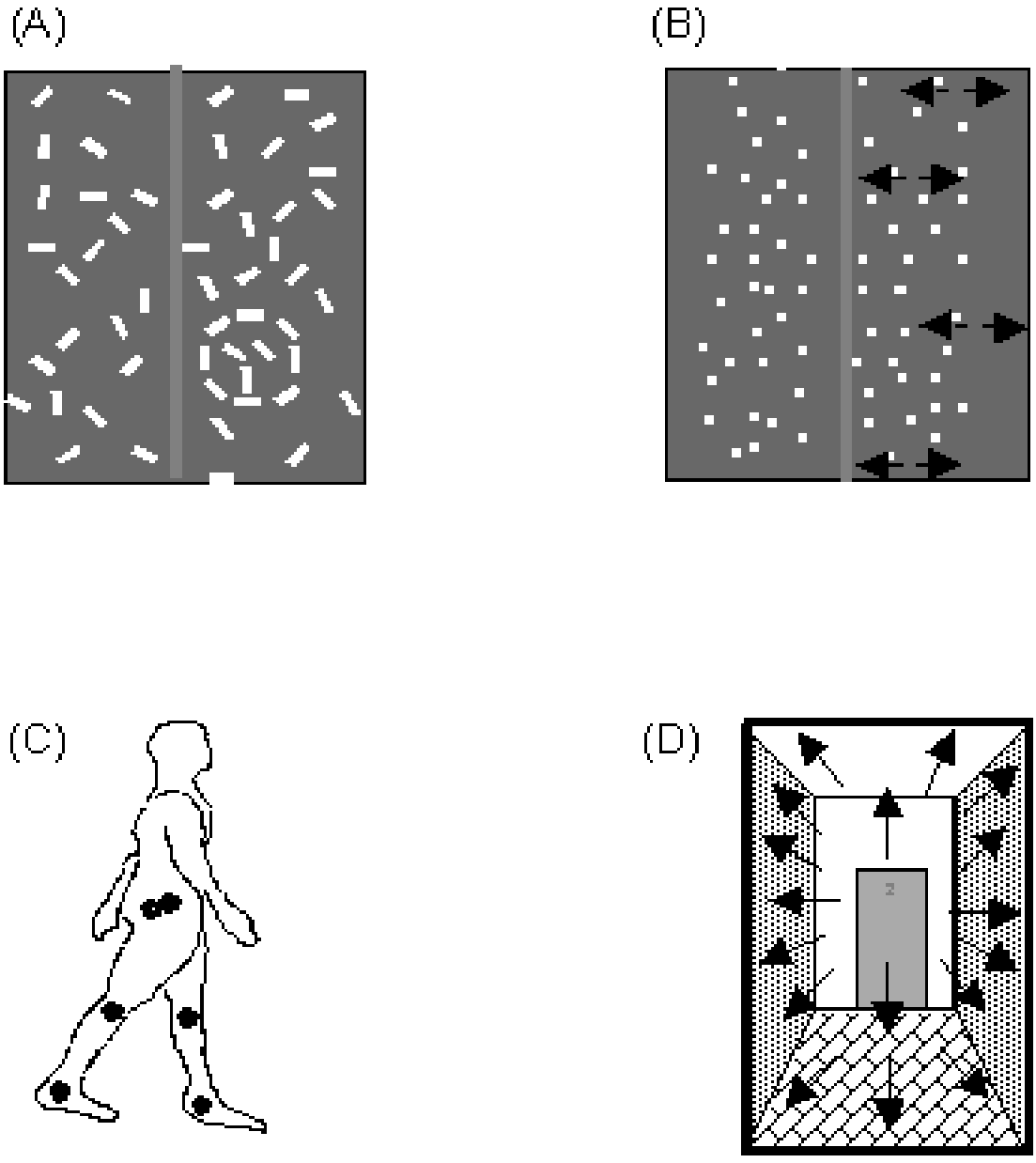
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Figure Caption Sheet

Figure 1:

Diagrammatic representations of the visual stimuli used in this study. (A) A static form coherence task adapted from Hansen et al. (2001). Participants report with a button press whether the left or right side of the display contains a coherent circular shape. (B) A visual motion coherence task adapted from Hansen et al. (2001). Participants report with a button press whether the left or right side of the display contains a subset of dots that translate coherently. (C) A biological motion perception task. Point-light stimuli depicted the lower half of a walking person's body. Six points indicate the dynamic locations of the walker's hips, knees, and ankles. The outline is a person is included here for illustrative purposes and did not appear in the experimental stimuli. (D) Optic flow task. Participants stood on a force plate while wearing a head mounted display. The display depicted either the optic flow that would be produced if the participant walked down a hallway (shown here) or a static image of a computer desktop (not shown).

Figure 1



***Highlights**

- Participants with Asperger's Syndrome (AS) scored significantly lower than a control group on measures of motor skills.
- Better motor performance was associated with better postural stability when viewing a visually dynamic virtual reality scene, and participants with AS showed significantly more postural sway than controls.
- Better motor performance was also associated with better visual sensitivity to biological motion, and participants with AS showed less sensitivity to human motion than controls.
- Better motor performance was also associated with increased sensitivity to motion perception; however, there were no differences between groups on random dot kinematograms, nor in terms of visual form perception.
- This may suggest that motor difficulties in AS may be related to perceptual deficits in visual sensitivity to dynamic information.