J Autism Dev Disord (2012) 42:557–565
DOI 10.1007/s10803-011-1267-0

ORIGINAL PAPER

IQ Predicts Biological Motion Perception in Autism Spectrum Disorders

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Published online: 3 May 2011

Abstract Biological motion is easily perceived by neurotypical observers when encoded in point-light displays. Some but not all relevant research shows significant deficits in biological motion perception among those with ASD, especially with respect to emotional displays. We tested adults with and without ASD on the perception of masked biological motion and the perception of direction from coherent and scrambled biological motion. Within the autism spectrum group, there was a large and statistically significant relationship between IQ and the ability to perceive directionality in masked biological motion. There were no group differences in sensitivity to biological motion or the ability to identify the direction of motion. Possible explanations are discussed, including the possible use of compensatory strategies in high IQ ASD.

Keywords Biological motion · Cognitive strategy · Social perception

Autism spectrum disorders (ASD) are developmental disorders characterized by (1) atypical development in social cognition, (2) delays in communication and language development and (3) idiosyncratic, repetitive behaviours and interests. The social cognitive abnormalities in ASD are arguably the most clinically profound deficits. There is a plethora of evidence that social perception is affected in ASD (Maestro et al. 2002; Abell et al. 2000; Klin 2000; Bowler and Thommen 2000; Castelli et al. 2002), and some evidence that animate motion is perceived or interpreted differently by those with ASD (Rutherford et al. 2006; Salter et al. 2008). In this study, we use the perception of biological motion as a tool for probing social perception in those with ASD.

Research regarding the perception of biological motion has often employed point-light-walker displays, in which a moving human or animal figure is represented by points of light on its joints. Originally, Johansson created the point light stimuli by attaching small light sources on the joints of human actors and then filming the actors moving about in the dark. Observers of these films reported a compelling perception of human motion although they could actually only see a small number of isolated lights (Johansson 1973). Subsequent research has often relied on computer-generated point-light displays, which are also effective in evoking compelling perceptions of human motion. Subjects can even reliably judge whether the actor is male or female (Barclay et al. 1978; Mather and Murdoch 1994; Troje 2002) and can recognize their friends (Cutting and Kozlowski 1977) and themselves (Beardsworth and Buckner 1981) based on gait (Jokisch et al. 2006).

Based on this and other evidence, it seems clear that these degraded motion cues are sufficient to extract meaningful information of social and biological relevance. This information can be conveyed both in the articulated motion-mediated shape that can be recovered from the coordinated motion of the dots, and also from signatures inherent to the local movements of individual dots (Troje 2008). Interestingly, both types of motion information are susceptible to pronounced inversion effects (Troje and Westhoff 2006) in normal observers. Inversion effects can be assumed to be indicative of the degree of specialization

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to a given stimulus class and thus provide an important tool for the assessment of stimulus-specific visual processing.

Several researchers have proposed that the core and causal psychological deficits in autism are lower-level differences in sensory and perceptual information processing (Dakin and Frith 2005; Happé and Frith 2006; Mottron et al. 2006) and deficits in social cognition are known to be both universal and severe in autism. Therefore, a deficit in the perception of biological motion in point-light-walker displays would be predicted, and some recent studies have reported experiments in which those with ASD observe biological motion displays. Moore et al. (1997) tested children and adolescents on their ability to perceive action and attitudes based on the motion of a figure in a point-light walker display. The first of three experiments showed that those with ASD were equally able to detect the motion of a human figure in a point-light display, when the minimum exposure time necessary for detection was compared. In the second experiment, verbal descriptions of point-light displays were analyzed after participants watched a clip designed to convey an emotion. The ASD group was less likely to spontaneously use emotion terms to describe these displays. In the third experiment, participants watched these emotion displays, plus displays depicting non-emotion states such as "itchy", "cold" or "hurt." Raters blind to diagnosis coded participants' verbal attempts to describe what the actor was "doing" (in action trials) or "feeling" (in emotion and state trials). Those with autism were significantly impaired, compared to matched control groups, in their ability to correctly attribute emotions and non-emotional states (Moore et al. 1997).

Subsequently Blake and colleagues asked a group of children aged 8–10 with ASD and an IQ matched control group to perform two visual tasks. In the biological motion task, children reported whether they saw a "person" or "not a person" after seeing a 1-s display showing one of several human activities portrayed by an unmasked point-light animation, either normal or scrambled. The autism group was significantly less sensitive to the biological motion. In a control condition, the children were asked to identify a rigid shape in a masked background, and the two groups did not differ on this non-social visual task (Blake et al. 2003). Similar results, supporting the idea that those with ASD perceive biological motion less accurately than controls, have been found more recently (Atkinson 2009; Congiu et al. 2010).

Another experiment found autism-related deficits in the perception of biological motion, but only for the perception of emotion, not for the perception of actions (Hubert et al. 2006). This finding is consistent with the broadly recognized group differences in emotion perception, found in displays that do not involve point light walkers (Celani et al. 1999). In Hubert et al.'s study, nineteen young adults in an ASD group and another 19 in a control group were asked to verbally describe a point light display in terms of action (e.g. jumping, digging, running), emotion (e.g. sad, frightened, angry), subjective state (e.g. itchy, tired, cold), and object (e.g. ironing board, brush, saw). The labels that the subjects produced were judged by experimenters as either correct or incorrect. The groups differed significantly only on the emotion trials (Hubert et al. 2006).

Similarly, Parron et al. (2008) compared 23 ASD and 23 control children describing displays that were similar to the emotion, subjective state and action displays used by Moore et al. (1997). This group found deficits with respect to accuracy in describing emotions conveyed in point light displays, but not a person's actions or subjective states, nor the movement of common artifacts displayed in control trials. The authors concluded that the deficit is specific to emotion perception, not the interpretation of complex movement.

Other evidence of an ASD specific impairment in the visual perception of emotions comes from Atkinson (2009). In this study, adults with ASD and matched controls watched both point-light and full-body displays of emotion and random-dot displays from which participants had to detect coherent motion. Those with ASD were impaired, as a group, on all three tasks. Moreover, there was a relationship between accuracy in the motion coherence task and the emotion perception task in the ASD group, but not in the control group (Atkinson 2009).

In addition, one case study found evidence that a 15-month old with ASD showed impairment in the detection of a point light walker (Klin and Jones 2008). Following that discovery, the authors conducted a control experiment that showed that unlike typically developing 2-year-olds, those with ASD do not preferentially orient to biological motion stimuli. Instead, they orient to non-social physical contingencies that may be found in point light walker displays and other displays (Klin et al. 2009).

A recent MRI study shows group differences in neural activation while participants watched biological motion in a point-light display, as well as ASD specific deficits in detecting biological motion as measured by reaction time (Freitag et al. 2008). These authors suggest that their results can be explained either by deficits in higher-order motion perception or deficits in the integration of complex motion information.

In the current study, we tested for biological motion perception in ASD and in a control group by asking adult observers to complete two tasks. One was designed to test the observers' ability to perceptually organize the array of dots in the display into the articulated structure of a walking figure. The second task was aimed at the ability to derive information from the local motion of individual dots. Although other studies have evaluated participants with ASD with respect to their ability to detect human

walkers in a masked display (Koldewyn et al. 2010; Murphy et al. 2009), the careful distinction between these two aspects of biological motion perception and our comparison of biological motion across species depicted in the display are novel in the ASD literature.

In the first task, observers indicated, via key press, whether they saw a point light walker or not within a mask of additional dots. In each trial, observers were presented with a sequence of two displays, only one of which contained a coherent point light walker. Each display includes the same number of dots, moving along the same trajectory. The only difference between the two displays was the presence versus absence of a coherent biological shape. Thus, this test assesses the observers' ability to perceptually organize the dots into a coherent shape. In order to solve the task, they must detect the walker figure in a mask of dots that moves in the same way as the dots that constitute the target walker. Signatures in the local motion of the dots cannot be used to solve the task.

In the second task, observes indicated, again via key press, whether the point light walker was facing to the left or the right. The walker was, in fact, stationary within the display, and was masked with stationary, flickering dots. In half of the trials, the walkers were shown in their veridical, coherent shape, while in the other half of the trials, the walkers were spatially scrambled. This latter condition is the more interesting one and complements the condition of the first task: While local motion was rendered useless in the first task, it provided the only available cues to direction in the second task.

Importantly, in the current study we were interested in within-group individual differences in the perception of biological motion, as well as between-group differences. Autism constitutes a spectrum, with some people showing greater severity of autistic characteristics, and other people showing fewer or milder symptoms. These differences are measurable using standardized measures such as the Autism Diagnostic Observation Scales (Lord et al. 2000). Furthermore, people on the autism spectrum have a range of intellectual functioning, measurable by standardized IQ tests such as the WAIS (Wechsler 1997). In addition to testing for an autistic effect on biological motion by comparing an ASD to a control group, we are interested in whether either the severity of autistic characteristic or the level of intellectual functioning will predict biological motion perception.

Method

Participants

Twenty-eight volunteers participated in the experiment. The ASD group consisted of 14 adults (14 male) with autism spectrum disorders, and a matched control group consisted of 14 adults (14 male) without any developmental disorders (see Table 1). Participants in the autism group were recruited via referral from a clinical specialist treating autism spectrum disorders. All participants in the ASD group had previously received clinical diagnoses of autism or Asperger Syndrome before entering the study, and one of the authors (MDR) confirmed their diagnoses via two criteria: (1) Autism Diagnostic Interview (ADI-R) (Lord et al. 1994) and (2) the Autism Diagnostic Observation Schedule (ADOS-G) (Lord et al. 2000). They were free from other known medical, developmental or psychiatric diagnoses. Participants in the control group were recruited from the community (that is, they were not university students) through a newspaper advertisement. Participants from the two groups were matched for age, sex, education level and IQ. Table 1 shows the mean IQ scores and age for each group.

All participants were given the Wechsler Adult Intelligence Scales (WAIS), which yields verbal, performance and full scale IQ scores (Wechsler 1997). Mean full scale IQ score was 94.6 (SD = 10.3) for the control group and 98.1 (SD = 13.61) for the ASD group.

Stimuli and Apparatus

Visual stimuli were presented on a 19″ CRT color monitor (with .25 mm dot pitch, 1280_1024 pixels spatial resolution, 85 Hz refresh rate), and responses were recorded via a keyboard. A Dell computer recorded responses and controlled stimulus presentation. The stimuli were generated using MATLAB (Mathworks, Natick, MA) and the Psychophysics Toolbox extension (Brainard 1997; Pelli 1997).

Table 1 Demographic information for all participants

No. of subjects	Gender (m/f)	Mean age (SD)	FSIQ (SD)	PIQ (SD)	VIQ (SD)	ADOS (SD)
Control group						
14	14	31 (9)	94.6 (10.3)	90.9 (12.3)	97.6 (10.0)	N/A
Autism spectrum group						
14	14	29 (6)	98.1 (13.61)	94.8 (11.6)	100.1 (18.1	15.6 (3.7)

The point-light figures subtended visual angles of 2.1 × 4.6°, 4.6 × 2.4°, and 3.6 × 3.6° for the human, cat, and pigeon, respectively, on a 6.4 × 6.4° field. All stimuli appeared as white dots on a black background.

The walker stimuli appeared as one of three types: a walking human, cat or pigeon. The human walker was computed as the average walker from motion-captured data of 50 men and 50 women (Troje 2002) and was displayed as a set of 11 dots. The cat walker was created from a video of a cat walking on a treadmill, and was represented as 14 dots. The pigeon walker was created from motion-captured data of a single pigeon walking, and was displayed as a set of 11 dots. All walkers appeared in sagittal view and appeared to walk in place rather than translate across the screen. Gait frequencies were .93 Hz for the human, 1.7 Hz for the cat and 1.6 Hz for the pigeon, reflecting realistic frequencies.

Scrambled walkers were created by randomly displacing the trajectory of individual dots within the same area that was covered by the coherent point-light display. Scrambled walkers also provided the basis for the mask used for the first (detection) task. In this case, the dots sampled from a normal coherent walker were re-located to a randomly selected location within the whole display area. In the case of walker-absent trials in task one, an additional scrambled walker was added to the mask to equate the total number of dots in both conditions.

The mask used for the second task (direction discrimination) was different. It consisted of stationary dots at random locations each lasting for 200 ms on the screen, after which each disappeared and was replaced with a new dot at a new location. All masking dots were identical to the dots constituting the walker.

In the detection task the number of the scrambled walker masking dots was either 20, 40 or 80. In the direction discrimination task, the number of the stationary flickering masking dots was either 50, 150, or 450.

Procedure

The Wechsler Adult Intelligence Scales (WAIS) (Wechsler 1997) was administered during a session prior to the test session. For the ASD group only, the Autism Diagnostic Interview (ADI-R) (Lord et al. 1994) and ADOS (Lord et al. 2000) had also been administered prior to the testing session. The main experimental testing session began with a description of the procedure and the observer signing a consent form. Participants then were provided with verbal instructions and visual illustrations of each task before beginning the experiment. All participants were tested binocularly sitting at a distance of approximately 50 cm to the computer screen in a dimly lit room. Each testing session was completed in one visit and lasted approximately 40 min.

Each participant first completed the "detection" task and then the "direction" task, always in that order. Each trial type is described below.

Detection of Biological Motion in Scrambled Walker Mask

The detection task was a two-alternative forced-choice task. Observers sequentially saw two displays. Each lasted 1 s and the two were separated by a .5 s interstimulus interval during which the screen remained blank. In one display, a coherent walker was embedded into the scrambled-walker mask, and in the other display the walker was replaced with an additional scrambled walker. The only difference between displays was the presence of a coherent shape. If the walker was in the first display, the observer was to press the left arrow, if in the second display, the right arrow.

The test block consisted of 360 trials. The factors animal type (human, cat, pigeon), mask density (20, 40, 80 dots), orientation (upright or inverted), and facing direction (left or right) were all counterbalanced. Presentation order was randomized. Feedback was not given.

Perception of Direction of Scrambled Walkers

For the "direction" task, observers saw a single 1 s display that showed either a coherent or a scrambled walker in a random dot mask. The task was to indicate via key press whether the walker was facing right or left. There was a practice block of 12 trials that showed unmasked versions of all trials.

The test block consisted of 360 trials, with 4 within-subject variables: animal, inversion, mask density, and scrambling. The factors animal type (human, cat, pigeon), mask density (50, 150, 450 dots), orientation (upright or inverted), and facing direction (left or right) were all counterbalanced. Presentation order was randomized. Feedback was not given.

The critical trials were those in which the walker was scrambled. In such trials, the only information about direction were the local trajectories of the individual dots. The coherent walker trials were included in order to make the experiment more rewarding and less frustrating for observers.

Results

Analyses for the detection and the direction tasks were separate. For all analyses the proportion correct is the dependent variable. As both tasks were 2AFC, chance performance corresponds to a rate of .5. For each of these

two tasks, we analysed group difference on performance. Individual differences are probed by comparing performance on each task to IQ and ADOS scores.

Detection of Biological Motion in Scrambled Walker Mask

One subject in the ASD group was excluded from analyses because his responses were at chance in both tasks. Duplicate analyses that included his data revealed the same pattern of significant findings as those reported below.

Within Subject Effects

For the detection task, there were three within-subject variables: animal, inversion, and mask. Pooling the ASD and the control groups together, there was a significant effect of inversion. Overall performance on upright trials (.67) was significantly different from performance on inverted trials (.59) ($F(1, 25) = 20.81$, $p < .001$).

There were also significant effects of masking. Performance was different across masking levels, with best performance with 20 dots (.68), then 40 dots (.63) and worst performance with 80 dots (.58) ($F(2,50) = 17.73$, $p < .001$).

Overall performance was significantly affected by the animal in the display. Proportions correct for human trials (.65) cat trials (.64) and pigeon trials (.60) showed significantly diminished performance with non-human and especially non-mammalian walkers ($F(2, 50) = 5.10$, $p = .01$).

Group Differences

The ASD group and the control group did not perform significantly differently overall. Overall, the proportion of correct responses was essentially the same for the ASD group (.66) and the control group (.61) ($F(1, 25) = 1.06$, n.s.).

There was no interaction between inversion and group, and the ASD group showed a very similar relationship between upright (.71) and inverted (.61) trials as the control group (.64 and .57, respectively) did ($F(1, 25) = .70$, n.s.).

There was no interaction between mask and group. ASD observers showed a decline in performance from masks of 20 dots (.72) to 40 dots (.66) to 80 dots (.60), which was similar in performance of control participants viewing masks of 20 dots (.65) 40 dots (.60) and 80 dots (.57) ($F(2, 50) = .47$, n.s.).

There was also no interaction between animal type and group ($F(2, 50) = .83$, n.s.). Both groups showed similar changes in performance. The ASD group's performance across animal type was human (.69), cat (.68), pigeon (.62), and the control group's was human (.62), cat (.61) pigeon (.59).

Predictors of Individual Performance

Our next analyses were attempts to predict individual differences in performance on the detection task. All observers had participated in a WAIS assessment, yielding a verbal IQ (VIQ), a performance IQ (PIQ) and a full-scale IQ score for each observer. In addition, observers in the ASD condition had participated in an ADOS assessment, which yields a score on a continuum in which higher numbers indicate more severe autistic characteristics. We assessed the predictive value of these parameters for each group separately, using correlational analyses.

For the ASD group, neither the overall IQ score nor the partial IQ scores were significantly correlated with overall performance: for PIQ ($r = .52$, n.s.) and FSIQ ($r = .50$, n.s.). Relationships between IQ scores and performance on upright trials alone also failed to reach significance: for VIQ ($r = .47$, n.s.) PIQ ($r = .47$, n.s.) and FSIQ ($r = .49$, n.s.). For the specificity of detecting human walkers, we calculated the relative advantage of a human walker over a non-human one by subtracting average performance on non-human trials from performance on human trials. The positive relationship between these human specificity scores and the social scores on the ADOS scores did not reach significance ($r = .46$, n.s.) nor was human specificity correlated with IQ scores: VIQ ($r = .50$, n.s.) PIQ ($r = .47$, n.s.) and FSIQ ($r = .50$, n.s.).

For the control group, IQ scores were not significantly correlated with overall performance for PIQ ($r = .49$, n.s.) or FSIQ ($r = .52$, n.s.). Relationships between IQ scores and performance on upright trials alone did not reach significance for PIQ ($r = .51$, n.s.) or FSIQ ($r = .50$, n.s.).

Perception of Direction

Within Subject Effects

For the direction trials, there were four within-subject variables: animal, inversion, mask and coherency. Pooling the ASD and the control groups together, overall performance was not significantly affected by animal. Proportions correct for human trials (.68) cat trials (.66) and pigeon trials (.68) were essentially the same ($F(2, 52) = .96$, n.s.).

In contrast, there were significant effects of inversion, masking and coherency. Performance on upright trials (.80) was significantly higher than performance on inverted trials (.54) ($F(2, 52) = 73.80$, $p < .001$). Performance was also significantly affected by masking levels, with best performance with 50 dots (.70), then 150 dots (.68) and worst performance with 450 dots (.63) ($F(2, 50) = 14.39$, $p < .001$). Finally, there was a strong and significant affect of coherency, with overall performance for non-scrambled

walkers (.77) being much better than performance for scrambled walkers (.57) (F (1, 25) = 101.31, $p < 001$).

There were several significant interactions: There was an animal by inversion interaction (F (2, 50) = 5.73, $p = .006$), revealing that inversion had the highest cost for the pigeon display and least cost for human walker. Performance on upright human, cat and pigeon trials was .79, .78 and .83 respectively. For comparison, inverted human, cat and pigeon trials yielded performance of .56, .53 and .52 respectively.

There was a significant animal by mask interaction (F (4, 100) = 5.38, $p = .001$): The cat and the pigeon were harder to detect in a mask than the human was. In other words, the human walker was harder to mask. Comparing masks of 50, 150 and 450 dots on human point-light displays yielded performance of .68, .68 and .67, showing very little effect of masking. Across increasing levels of masking for cat trials, performance changed from .69 to .68 to .60 demonstrating a greater effect of masking. Finally masking across pigeon trials showed the greatest effect, from .73 to .69 to .61.

Coherence by inversion yielded a significant interaction (F (1, 25) = 12.74, $p = .001$). There was a greater cost of scrambling in upright trails, from .93 to .67, than in inverted trials, which changed from .61 to .47 when scrambling was added.

We also found two three-way interactions. Animal by coherence by inversion was a significant interaction (F (2, 50) = 14.80, $p < .001$). Adding scramble was particularly disruptive to the perception of the upright walkers, particularly the human and the cat. In contrast, adding scramble was equally disruptive to pigeon perception regardless of inversion.

Coherence by mask by inversion was also a significant three-way interaction (F (2, 50) = 3.34, $p = .04$). For upright walkers, scrambling had a big effect if the walker was masked.

Group Differences

The ASD group and the control group did not perform significantly differently. Regarding overall performance, the proportion of trials correct was essentially the same for the ASD group (.67) and the control group (.67) (F (1, 25) = .007, n.s.).

Again, there was no interaction between inversion and group (F (1, 25) = 2.95, n.s.). The autism group's performance on upright trails (.82) was better than performance on inverted trials (.51), which was true for the control group as well (.78 and .56, respectively).

There was also no interaction between mask and group (F (2, 50) = 1.67, n.s.). The autism group showed a cost of added masking, from 50 dots (.69) to 150 dots (.67) to 450 dots (.64). Similarly, the control group showed a cost of added masking, from 50 dots (.71) to 150 dots (.69) to 450 dots (.61).

Finally, there was no group by coherence interaction (F (1, 25) = .43, n.s.). The ASD group performed better on the coherent (.76) than scrambled trials (.58) as did the control group (.78 and .57, respectively).

There was an interaction between animal and group, for these direction trials (F (2, 50) = 3.10, $p = .05$). Those in the ASD group did not show a cost of animal as they viewed humans (.66) cats (.65) and pigeons (.70), whereas control participants were slightly better on trials with humans (.69) compared to cats (.67) and pigeons (.66).

Predictors of Individual Performance

We next used IQ and ADOS scores to predict performance on the direction task. We assessed individual predictor scores for each group separately, using correlational analyses. For the ASD group, IQ scores were strongly and significantly predictive of overall performance on the direction task. Overall performance correlated with VIQ ($r = .57$, $p < .05$) with PIQ ($r = .62$, $p < .05$) and with FSIQ ($r = .70$, $p < .01$), as illustrated in Fig. 1. Scores on the ADOS seems negatively correlated with overall performance, but the relationship does not reach significance ($r = -.46$, n.s.).

Again considering the ASD group's performance on direction trials, full Scale IQ (apparently driven by Verbal IQ) was a significant predictor of the effect of inversion: VIQ ($r = -.65$, $p < .05$) PIQ ($r = -.33$, n.s.) and FSIQ

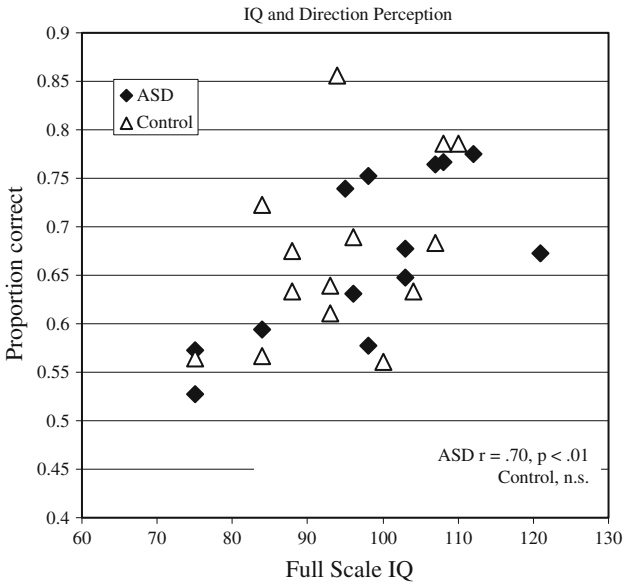

Fig. 1 For the ASD group in the direction experiment, there was a significant correlation between IQ and overall performance

($r = -.62$, $p < .05$). People with higher IQ scores were less affected by the inversion of the walker. There is a positive relationship between VIQ and the cost of scrambling the walker ($r = .59$, $p < .05$). People with higher IQ scores were more influenced by the scrambling of the walker than people with lower IQ.

For the control group, there was no significant relationship between PIQ scores and overall performance. Overall scores compared to FSIQ, which was significant in the ASD group yielded a correlation coefficient of .45 (n.s). FSIQ was a predictor for effects of animal ($r = -.53$, $p < .05$): Observers with lower IQ scores were less likely to be affected as the human model was replaced with a cat or pigeon model. Other relationships were not significant.

Analyses of Scrambled Trials Alone

In the direction experiment, scrambled trials were especially interesting. This is true because in the scrambled trials, only the local motion of individual dots is available to inform the observers about direction. Global, motion-mediated shape could not be used to infer direction.

For the ASD group in the direction trial, when scrambled trials alone were analysed, there was a significant negative correlation between verbal IQ and the inversion effect ($r = -.58$, $p = .037$). Inversion effect was the difference between performance on upright and inverted trials. In other words, for higher IQ individuals, there was a lower cost of inversion than there was for lower IQ individuals. Other correlations between IQ and the effects of inversion, mask and animal were not significant, including the correlation between inversion effect and FSIQ ($r = -.475$, $p = .1$).

Discussion

With respect to the perception of biological motion, we found no group differences in the detection of a masked point-light walker, or in the perception of the direction of motion. Furthermore, the pattern of decline across levels of masking and the species depicted in the display was similar between groups. This finding is not inconsistent with other published work. Although others have found evidence of impairments with respect to emotion perception (Hubert et al. 2006; Atkinson 2009; Parron et al. 2008; Moore et al. 1997) those who have asked those with ASD to detect biological motion in non-emotional displays have often found no group differences (Murphy et al. 2009). It may be that social and emotional processing is critical in explaining the ASD deficit sometimes seen in biological motion perception. That said, some recent work does find group effects in the detection of non-emotional point-light displays (Koldewyn et al. 2010; Blake et al. 2003).

There are a few methodological differences between this study and those that have found an ASD deficit in non-emotional biological motion perception, some or all of which may account for differences in the findings. First, our subjects were slightly older, with a mean age of 29 years. Participants in the Blake et al. (2003) study were 8–10 year old children, and participants in the Koldewyn et al. (2010) study were adolescents with a mean age of 15. These age differences are consistent with the idea that there is simply a delay in the development of biological motion perception in those with ASD, and that the ability does eventually develop, either via typical processes or via alternative, perhaps more deliberate strategies.

Second, the task in the study by Blake and colleagues (2003) required participants to respond to displays depicting a variety of different activities and to discriminate between coherent and scrambled versions. In contrast, our stimuli were all based on walking. Walking is a rather stereotypic behaviour that may not provide enough room for socially relevant information to lead to group differences. While the detection task probes the ability to retrieve the global, overall, articulated structure of the walker, the direction task, particularly the scrambled motion trials, tests for the ability to exploit cues contained in local motion.

The other past study that showed strong group differences found those differences only for trials in which the observer was asked to label an emotion, and found no group differences in other trial types (Hubert et al. 2006). As we report no emotion recognition trials, our results do not directly contradict those of Hubert and colleagues.

Within our ASD group, performance on a biological motion perception task was significantly correlated with IQ. Performance on our identification of direction task, which required observers to report the direction of motion for a masked and sometimes scrambled figures was predicted by IQ for the ASD group. Indeed, performance on the direction task was positively correlated with FSIQ as well as PIQ and VIQ. Importantly, even in the scrambled condition, which requires observers to detect motion based on local information, performance was positively correlated with PIQ.

Within the ASD group, higher IQ also predicted a significantly smaller impact of inversion: those with higher IQ could better discern directionality despite inversion. Only IQ, and not severity of autism as measured by the ADOS, predicted biological motion performance. Some past research on the perception of biological motion has also found IQ to be a predictor in an ASD group. For example, Atkinson found that VIQ (but not PIQ) was correlated with accuracy in identifying emotions portrayed by a point-light-walker display. Koldewyn et al. (2010) reported a correlation between IQ and performance on a biological

motion detection task in an ASD group, but not in a matched control group. However, others have not reported such a relationship. Parron et al. (2008) reported that there was no relationship between IQ and the accuracy of reporting emotions and subjective states portrayed by point-light displays.

It is possible that this finding reveals the use of compensatory strategies. Perhaps those with higher IQ are better able to create or observe strategies that might be reliably employed in service of biological motion perception despite lacking intuitive social perceptual processing. Consistent with this possibility are the recent finding of a relationship between performance on a motion coherence detection task and performance on a biological motion perception task in an ASD group (Koldewyn et al. 2010) and the finding that motion coherence thresholds predicted performance on a biological motion perception task in an ASD group but not a control group (Atkinson 2009). Although not conclusive, these findings are consistent with the idea that while control participants are relying on specialized social perceptual processes in a biological motion task, those with ASD are recruiting processes that are specialized for non-social perceptual processes, specifically, a more general motion-processing mechanism.

In support of this alternative cognitive heuristics idea is the finding that when scrambled trials alone are analysed, the ASD group shows a negative correlation between verbal IQ and inversion effect in the direction task. Higher IQ individuals were less affected by the inversion. Another way to say this is that higher IQ individuals were more likely to have found a successful strategy, and the strategy they were using was less hindered by inversion. The information contained in upright and inverted stimuli is, of course, the same. Inversion effects thus reflect a perceptual system's inherent inability to exploit the information, a sign of specialization. What might make sense for a visual filter with an evolutionary history may not be true for a cognitive surrogate strategy. If it can work on upright stimuli there is no reason to assume why it should not work on inverted versions.

For the direction trials, but not the detection trials, there was a significant group by animal interaction. The control group showed a steady but small decline in performance as the walker changed from human to non-human to non-mammalian, while the ASD group did not show this pattern. Indeed, if anything, performance was best for the pigeon trials among ASD observers. Perhaps something about the directional information in the motion of the walker is not affected by the global perception of specific types of animals for the ASD group. As a group, those with ASD were more indifferent to the species they were viewing. Note that results might be expected to be different had participants been asked to classify or label walkers by species. In our task they merely had to detect the presence or the direction of the walker. Classification and labelling might have presented more of a challenge to an ASD group, and resulted in poorer performance, compared to the control group.

It is interesting to notice that there were no group effects, interactions, or differences in individual predictor scores in the detection experiment. All of the group effects that we saw were from the direction experiment. In other words, we show no evidence that there is an autism specific deficit in detecting biological motion based on motion-mediated structure, which is in agreement with Hubert and colleagues' findings (Hubert et al. 2006) but in contrast with Blake and colleagues' findings (Blake et al. 2003).

This study contributes to a growing literature on the question of whether there is an autism-specific deficit in the perception of biological motion. In two separate tasks, one addressing global perceptual organization and one inference of information from local motion, our ASD group did not show significantly different performance from the control group. Past published results have been mixed, some finding group differences and some not, with respect to autism-specific deficits in biological motion perception. Our results are at odds with some past research that has found group differences, but also differ methodologically from those studies.

Notice also that with the data for the two groups combined, animal had a significant effect for the detection experiment, but not for the direction experiment. This is consistent with past work suggesting that the human visual system is very sensitive to motion information in the foot movement patterns of terrestrial animals (Troje and Westhoff 2006; Chang and Troje 2009). The motion of the foot can reveal directional information regardless of the global form of the walker. Resilience of the specific local information is robust with respect to the human visual system.

As we continue this line of study, we plan to include tasks that require observers to identify actions as well as emotions and mental states. We expect that those tasks involving social perception, such as the identification of emotions and mental states based on motion cues alone will be related to the severity of autistic symptoms, as measured by the ADOS.

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