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No evidence for a fundamental visual motion processing deficit in autism spectrum disorders

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Running title: Visual motion processing in ASD

Lay Abstract

Individuals with autism spectrum disorders (ASD) have complex social and communication difficulties. It has been suggested that these difficulties might be partly driven by very basic differences in visual perception, but results to date have been mixed. In the largest study of its kind, we tested adolescents both with and without ASD on three measures of basic visual processing: motion coherence, form-from-motion, and biological motion. For the groups as a whole, we found no evidence of differences between those with and without ASD suggesting that there is no fundamental visual motion processing deficit in individuals with an ASD, at least by adolescence. However, we did find a subgroup of individuals with ASD (approximately one in five of the sample) who had a low IQ and who had exceptionally poor biological motion processing abilities. Biological motion is the motion that an animate object makes and recognising it is important for social-cognitive understanding. For both groups, we also found a positive correlation in performance between the biological motion task and the Frith-Happé animations, a task that requires the interpretation of the thinking patterns and ‘mental states’ of two small cartoon triangles. We argue that this association reflects that both are tasks that involve social cognition and use the same part of the brain, the superior temporal sulcus..

Word count = 215 (limit 250)

Abstract

It has been suggested that atypicalities in low level visual processing contribute to the expression and development of the unusual cognitive and behavioural profile seen in autism spectrum disorders (ASD). However, previous investigations have yielded mixed results. In the largest study of its kind (ASD $n = 89$; non-ASD = 52; mean age 15 years 6 months) and testing across the spectrum of IQ (range 52-133), we investigated performance on three measures of basic visual processing: motion coherence, form-from-motion and biological motion. At the group level, we found no evidence of differences between the two groups on any of the tasks, suggesting that there is no fundamental visual motion processing deficit in individuals with an ASD, at least by adolescence. However, we identified a tail of individuals with ASD (18% of the sample) who had exceptionally poor biological motion processing abilities compared to the non-ASD group, and who were characterised by low IQ. For the entire sample of those both with and without ASD, performance on the biological motion task uniquely correlated with performance on the Frith-Happé animations, a higher-level task that demands the interpretation of moving, interacting agents in order to understand mental states. We hypothesise that this association reflects the shared social-cognitive characteristics of the two tasks, which have a common neural underpinning in the superior temporal sulcus.

Word count = 220 (limit 250)

Keywords: motion coherence, form-from-motion, biological motion, point light display, mentalising, theory of mind

Introduction

Despite decades of dedicated research, the causes of the behaviours that define autism spectrum disorders (ASD) remain enigmatic. An appealing line of enquiry is to characterise relatively low-level perceptual abilities in ASD, given that any atypicalities at this level could fundamentally alter the cascade that contributes to higher order cognition and behaviour. One such focus has been on motion coherence (MC) i.e. the ability to integrate basic moving visual signals (dots) into the perception of a coherently moving whole. Although some research has suggested that individuals with ASD have difficulties with this type of perception (e.g. Annaz et al., 2010; Atkinson, 2009; Milne et al., 2002; Pellicano et al., 2005; Spencer et al., 2000), many investigations have found no significant evidence of impairment (e.g. Del Viva, et al., 2006; de Jonge et al., 2007; Koldewyn et al., 2009; White et al., 2006). While the perception of MC indexes sensitivity to movement, the perception of static coherent form indexes the ability to integrate local visual stimuli across space into a meaningful whole. Results are less ambiguous, with most studies finding no evidence of difficulties in ASD (e.g. Blake et al., 2003; Del Viva, et al., 2006; Koldewyn et al., 2009; Milne et al., 2006; Spencer et al., 2000; White et al., 2006).

Many instances of visual perceptual processing require the perception of both form *and* motion and this is true of most socially relevant perceptual processing, including biological motion (BM) (e.g. Thirkettle et al., 2009). BM is the movement that an animate object makes and BM paradigms typically present animated point-light displays (PLD) that represent a human in motion; the observer uses the motion cues to extract information about form and perceive the PLD as a person. The perception of BM has been associated with the superior temporal sulcus (STS), particularly the posterior region (e.g. Grossman et al., 2000; Pyles et al., 2007), which is an area of the brain that receives input from lower level visual cortical pathways (Seltzer & Pandya, 1978). Further, this region is a core component of the ‘social brain’ (Pelphrey & Carter, 2008), which tallies with the social pertinence of perceiving BM. Individuals with ASD have

shown atypical processing of the STS during perception of BM (Freitag et al., 2008; Herrington et al., 2007), as well as attenuated perception of the stimuli (e.g. Blake et al., 2003; Kaiser et al., 2010; Koldewyn et al., 2009). Aligning with this, structural abnormalities within the STS have also been documented in ASD (Boddaert et al., 2004).

The motivation for the current study was twofold. First, given that previous data suggest that the visual processing of motion rather than static images might be compromised in ASD, we were interested in profiling performance across three ‘classes’ of motion perception (see Reiss et al., 2005). The tasks selected were MC, form-from-motion (FFM) and BM processing. . In FFM, a rigid form is defined by the coherent motion of a group of signals (e.g. dots), which appear within a background of signals moving with a contrasting motion; the BM task can be considered a specific type of FFM task. To date, only one study (Annaz et al., 2010) has presented this battery of tasks to individuals on the autism spectrum; our study uses an older age group (childhood vs. adolescence). Second, given that BM tasks activate the STS we wanted to explore the association between performance on this task and a higher-level ‘mentalising’ task that also activates the STS and on which individuals with ASD are known to be impaired, namely the Frith-Happé animations (Castelli et al., 2002). The Frith-Happé task requires interpretation of two moving, animate triangles that interact, and typically elicits complex mental state/social interpretations (e.g. coaxing, surprising). Thus both the BM task and the Frith-Happé animations contain a distinct social element that is defined by motion. We predicted impairment in the individuals with ASD on the MC and BM tasks, and for performance on the Frith-Happé animations to uniquely correlate with the perception of BM.

Method

Eighty-nine adolescents with an ASD (mean age=15 years 6 months (SD=6.1 months; range 14;9-16;9); 81 male) and 52 adolescents without an ASD (mean age =15;6 (SD=5.5; range 14;2-16;11); 49 male) were tested. These participants were part of a larger cohort of individuals (ASD N = 100; Non-ASD N = 57) who were participating in the Special Needs and Autism

Project (SNAP) cognitive phenotype study (see Charman, Jones, Pickles, Simonoff, & Happé, in press). Four of the 100 ASD participants were excluded for not being able to cope with the demands of the visual perception tasks. A further 12 (7 ASD; 5 non-ASD) did not have visual perception task data due to time constraints, program error or task availability. Of those successfully completing the tasks, the 89 participants with an ASD (49 childhood autism; 40 other ASD) and 24 of the participants without an ASD were recruited from the Special Needs and Autism Project cohort (SNAP; Baird et al., 2006; Charman et al., in press). Consensus clinical ICD-10 diagnoses for the SNAP cohort was made using the ADI-R (Lord, Rutter & Le Couteur, 1994) and ADOS-G (Lord, Risi, Lambrecht, Cook, Leventhal et al., 2000), alongside IQ, language and adaptive behaviour measures (see Baird et al., 2006 for details). The 24 SNAP participants in the non-ASD group did not meet clinical criteria for an ASD. Rather, they had a range of primary ICD-10 diagnoses (15 mild mental retardation; 2 moderate mental retardation; 3 specific reading/spelling disorder; 2 AD/HD; 1 expressive/receptive language disorder; 1 no diagnosis). The remaining non-ASD participants (n=28) were recruited locally from mainstream schools. Parent and teacher report confirmed that all were typically developing; none had a psychiatric or developmental diagnosis, a statement of special educational needs or were receiving medication. The Social Communication Questionnaire (SCQ; Rutter, Bailey & Lord, 2003) was collected from parents of 24 of the 28 adolescents; no individual scored 15 or above (the cut-off for ASD). For all participants, IQ was assessed using the Wechsler Abbreviated Scale of Intelligence (WASI^{UK}; Wechsler, 1999), with full-scale IQ of the total cohort ranging from 52-133. Using t-tests, there was no significant difference between groups for age, verbal IQ, performance IQ or full-scale IQ (all $p > .2$; see Table 1).

Tasks

Visual perception tasks

All tasks were programmed in Visual Basic and presented on a Hewlett Packard laptop computer with a 15" LCD display screen. Most participants were tested in one of two quiet testing labs.

For practical reasons, a minority were tested at home or at school in the best available testing space but always in a quiet 1:1 environment. Participants were positioned with their eyeline approximately 50 cm from the screen. The tasks were those used in Annaz et al., (2010), which in turn were based on Reiss et al., (2005). The three tasks were completed consecutively, presented in one of six counterbalanced orders. For each task trial, two black square panels were presented simultaneously and side-by-side on the display screen. The participant had to point to (or verbally indicate, if preferred) which of the panels contained the target motion/stimulus. The participant's responses were inputted by the experimenter, who also initiated each trial. Each task was preceded by a five trial practice, where feedback and discussion of their decision ensured that all participants understood the task. Feedback was not provided during the actual tasks.

The stimuli were comprised of white dots (0.23° visual angle in diameter) that could behave as signal or noise. Stimuli were presented on the black square panels ($13.69^\circ \times 13.69^\circ$ visual angle in height and width). Each trial was displayed until the participant responded, up to a maximum of 6000 ms, and at a rate of 25 frames/s. The direction of the target motion/stimulus (left or right) and the panel that contained the target motion/stimulus were randomised and counterbalanced across groups of eight trials. **Motion coherence (MC) task**

This task established a threshold for the ability to detect MC. Both panels contained randomly positioned white dots. Dots moved with translational motion and were either signal elements that moved coherently (i.e. in the same direction; at a rate of 2.5° visual angle/s) or random noise. Any dot meeting the edge of the panel would wrap around to the other side. Each dot had a lifespan of one frame (i.e. 40 ms), which is a standard procedure to prevent the task being solved by following a single dot, and was randomly assigned as signal or noise (see Newsome & Paré, 1988). The participant had to select the panel that contained the dots that “moved the same way”, with the experimenter visually using their hands to demonstrate the target movement. The experiment began with a starting trial, which presented 10 dots (either all

signal or all noise) in each panel. A detection threshold was established using a two-down/one-up adaptive staircase procedure. Following the first trial (where threshold value = 1.00), three noise dots were added to both panels after every two consecutive correct trials. An incorrect trial resulted in three noise dots being removed from each panel. A task was terminated after seven reversals of the staircase. The threshold score was calculated as the average signal-to-noise ratio (signal/signal + noise) of the seven reversals. The closer a threshold score was to zero, the better the participant performed. For the five practice trials, a set sequence of 0, 6, 6, 6, 3 noise elements were added/removed.

Form-from-motion (FFM) task

This task establishes a threshold for the ability to use motion cues to detect form. Each panel contained randomly positioned white dots that formed a rectangle ($6.87^\circ \times 4.58^\circ$ visual angle) set against a background (i.e. remaining panel space). Signal elements in the panels moved coherently (rate of 2.5° visual angle/s) to either the left or right, with the coherent motion in the rectangle moving in the opposite direction to the coherent motion of the background. Noise elements (i.e. dots with random motion) were also present in both the rectangle and background. In one panel the rectangle was positioned vertically and in the other it was positioned horizontally; the location of the rectangles within the panels was assigned randomly but with their borders at least 1.1° visual angle from each panel edge. As with the MC task, each dot had a lifespan of one frame and was randomly assigned as signal or noise. Also mimicking the MC task, any dot meeting the edge of the panel or the rectangle would wrap around to the other side and a panel dot meeting the edge of the rectangle would ‘jump’ to the other side. The participant was shown an example of the target shape (a solid outline of a vertical rectangle) and was asked “Where is the shape?”. The vertical rectangle icon was present on the computer screen throughout the task to remind participants of the target shape. Throughout the task the same number of dots remained on the screen: 185 dots in the background and 40 in the rectangle and with a density of 1.01 dots per degree. The experiment began with all dots moving coherently as

signal (i.e. in one coherent direction for the rectangle and in the opposite coherent direction for the background). An identical stepwise procedure and threshold calculation was used to the MC task but with the adjustment of coherence levels being task specific; for this task the proportion of signal vs. noise elements was adjusted, rather than noise dots being added or subtracted. When two consecutive trials were correct the proportion of noise elements increased by 5% (of 185 background dots and of 40 rectangle dots) and when a trial was incorrect the proportion of noise elements was reduced by 5% (of 185 background dots and of 40 rectangle dots). For the five practice trials, the number of noise elements were increased/decreased using a set sequence of 0, 25, 25, 50, 15% conversion.

Biological motion (BM) task

This task establishes a threshold for the ability to detect BM (point-light displays, PLD; Johansson, 1973) in noise. One display panel depicted a centrally positioned PLD of a man walking on the spot and in profile (approximately 6.5° visual angle in height). He was composed of 11 signal dots attached to the major joints (2 hands, 2 elbow, 1 shoulder, 2 feet, 2 knees, 1 hip) and head of an invisible human form. The other panel presented a spatially identical but temporally scrambled version of the PLD, with the trajectories of the dots played temporally out of phase with each other (e.g. instead of the dots representing a foot and knee moving forward together, they now might move in the opposite direction). This manipulation meant that the scrambled PLD did not resemble a person walking. The average velocity of the dots was equivalent to the rate of movement in the MC and FFM tasks. The participant had to point to the panel that contained the “man walking”. The first trial contained only the PLDs and no noise elements. Noise elements were dots that had the same trajectories as the PLD signal dots but were randomly positioned in the two panels. An identical stepwise procedure and threshold calculation was used to the MC task, i.e. three noise elements were added to each panel following two consecutive correct responses and three were removed following an incorrect

response. For the five practice trials, a set sequence of 0, 3, 3, 3, 6 noise elements were added/removed.

Examples of all stimuli can be seen in Figure 1.

Frith-Happé animations

The task used six silent 2D animations that are part of an established set of mental state cartoons, and previously described procedures were followed (see Abell et al., 2000 and Castelli et al., 2000 for further details). The animations were played on the same laptop computer as above but on an earlier testing day (on average 29 days (SD 36.6) earlier); the order of the animations was counterbalanced. All featured two interacting ‘characters’, a big red triangle and a small blue triangle, moving within a white framed space. We used four animations that depicted ‘theory of mind’ (ToM) interactions (coaxing, mocking, seducing, surprising) and two simpler animations that depicted goal-directed (GD) interactions (fighting, chasing). The animations were matched as closely as possible for visual characteristics. The length of the animations averaged at 41 seconds (SD=4.1 seconds). The participant had to watch the animation and to describe what they thought the two triangles were doing, with their verbal response recorded for later transcription and scoring. Three scores were calculated: (i) intentionality (degree of mental state attribution: scored from 0-5 with 0=no mental state language i.e. describing a non-deliberate action, and 5=sophisticated use of mental state language i.e. describing deliberate action with goal of affecting mental state), (ii) appropriateness (degree to which participant correctly identified the content of the animation: scored from 0-2 with 0=incorrect and 2=fully appropriate interpretation), (iii) length (length of response, scored from 0-4 with 0=no response or clause and 4=more than three clauses). Scoring was limited to three trained experimenters. For reliability purposes, two experimenters independently scored 72 of the 129 scripts (56%); intraclass correlations for the mean scores were high (range .82-.98), indicating good reliability. Any discrepancies in scoring between the two raters were resolved by

consensus agreement. The number of participants who completed the Frith-Happé animations was slightly less than those who completed the visual processing tasks (ASD=79; non-ASD=50). The age and IQ differences between these two subgroups remained non significant (all $p > .3$; See Table 1).

Results

Visual processing tasks

The mean threshold scores and standard deviations for the three visual processing tasks are presented in Table 2, with boxplots of the distributions shown in Figure 2. The Kolmogorov-Smirnov test indicated significant violations of the normal distribution but these were largely corrected by a \log^{10} transformation. All parametric analyses are conducted on the log transformed data. Analysis of group differences was conducted using a 3 (Task) x 2 (Group) mixed design ANOVA. A significant main effect of Task ($F(1,68)=81.06$; $p < .001$) but a non significant main effect of Group ($F(1)=0.23$; $p = .64$) were found. The Task x Group interaction was significant ($F(1,68)=3.90$; $p = .03$), driven by the ASD group performing relatively better than the non-ASD group on the MC task, but relatively worse on the other two tasks. However, post-hoc t-tests did not indicate that the groups were significantly different on any of the tasks (all $p > .1$).

Exploration of poorly performing subgroups

Given a priori predictions, we statistically tested for the presence of a subgroup of poor performers with ASD. Using a split of 1.65 SD from the control mean (following Milne et al., 2006 and White et al., 2006 and using the raw thresholds), we divided participants into whether they were 1.65 SD below the control mean performance or if they were above this cut-off. For the MC task, 1 person was >1.65 SD below the mean in the ASD group (i.e. 1.1% of the group) compared to 3 in the non-ASD group (5.8%). Using Fisher's Exact test, this difference in distribution was not significant ($p > .1$). For the FFM task, 9 (10.1%) were >1.65 SD below the mean in the ASD group compared to 3 (5.8%) in the non-ASD group ($p > .5$). For BM, 16 (18%)

in the ASD group were >1.65 SD below the control mean compared to 3 (5.8%) without ASD, which reached statistical significance ($p=.04$). For both diagnostic groups, the poorly performing subgroups were mutually exclusive, with the exception that 6 of the 16 with ASD and with poor BM were also in the poor FFM subgroup. . Compared to the remaining 73 individuals with ASD, the 16 participants with ASD and with poor BM had a significantly lower mean verbal (65.3 (SD=12.6) vs. 85.8 (16.5); $t(87)=4.68$; $p<.001$), performance (72.2 (14.7) vs. 95.6 (15.9); $t(87)=5.40$; $p<.001$) and full-scale IQ (66.3 (12.1) vs 89.7 (15.8); $t(87)=5.59$; $p<.001$). Additionally, they performed significantly worse on all three visual processing tasks (MC: .31 (.11) vs. .17 (.14); $t(87)=-4.25$; $p<.001$; FFM: .41 (.21) vs. .26 (.13); $t(80.01)=-12.16$; $p<.001$; BM: .60 (.07) vs. .35 (.11); $t(87)=-3.72$; $p<.001$). Although the subgroup of poor performers is characterised by low IQ, it is notable that 27 of the remaining 73 participants with ASD (37.0%) had a profile of verbal *and* performance IQ within the range of the poorly performing subgroup.

Frith-Happé animations

The visual processing scores for those completing the Frith-Happé animations were similar to those for the whole group, with no significant group differences found (t-tests all $p>.08$; see Table 2). The data were highly skewed and could not be satisfactorily corrected by a log transformation, so Mann-Whitney U non-parametric comparisons were used. For the ToM animations, the ASD group showed significant difficulty with intentionality ($U=1384.5$; $p=.004$) and appropriateness ($U=1315.0$; $p=.002$), but no difference in the length of utterances ($p>.1$). For the GD animations, the ASD group performed similarly for both intentionality ($p>.1$) and appropriateness ($p>.5$), although the length of utterances were significantly shorter ($U=1600.0$; $p=.046$). See Table 3.

Associations between the visual processing tasks

Using non-parametric spearman's rho correlations, in the ASD group all three visual processing tasks were negatively associated with full-scale IQ, whilst in the non-ASD group only the FFM and BM tasks correlated with IQ (NB. this pattern was identical for verbal and

performance IQ). For the ASD group, all three tasks were strongly positively intercorrelated and these associations were maintained even when the moderating effect of full-scale IQ was accounted for. There was no significant association between tasks in the non-ASD group (see Table 4).

Associations between the visual processing and Frith-Happé animations

Table 5 illustrates Spearman's rho correlations for the visual processing tasks and full-scale IQ with pertinent variables from the Frith-Happé animations. For both groups, the ToM items were significantly negatively correlated with the BM task indicating that better detection (a lower threshold) of BM was associated with higher ToM scores. The strength of this association was attenuated when full-scale IQ was controlled for but the association between ToM intentionality and BM for the ASD group and between ToM appropriateness and BM for the non-ASD group remain significant. For the GD items, only the ASD group showed a significant correlation with the BM task, and this was reduced to a trend ($p=.06$) when IQ was partialled out. As would be predicted from the correlations, the ASD subgroup with poor BM abilities (and with lower IQ) performed significantly more poorly than their peers with ASD on the ToM items, in terms of intentionality (2.2 (.8) vs. 3.0 (.9); $U=185.5$; $p=.003$) and with a strong trend for appropriateness (.4 (.3) vs. .6 (.5); $U=234.5$; $p=.051$). There was no significant difference between subgroups for the length of utterances ($p>.6$). For the GD items, there was a trend towards significant difficulty for appropriateness (1.4 (1.1) vs. 1.7 (.5); $U=281.0$; $p=.061$), but intentionality and length did not discriminate the subgroups (both $p>.3$).

Additional analyses were run to investigate whether the profile of performance differed between those with a diagnosis of 'childhood autism' vs. 'other ASD'. However, there was no indication in the data of the ASD group differing by diagnostic category.

Discussion

In the largest study of its kind and testing across the range of IQ, we find no evidence that adolescents with ASD have fundamental difficulties with the perception of MC, FFM or BM.

The data indicate a tail of individuals with ASD (18% of the ASD sample) who have exceptionally poor BM, although these individuals were also characterised by low intellectual ability and poor relative performance across all tasks. In demonstrating a specific association between performance on the BM task and the Frith-Happé animations, which necessitated understanding of the mental states of moving agents, we support the suggestion that performance on both tasks is associated with the same neurological structure, namely the STS.

No evidence of poor motion coherence or form-from-motion in ASD

Consistent with a number of studies of MC (see Kaiser & Schiffrar, 2009 for a review), we found no evidence of impairment in our adolescents with ASD on this task. The visual motion area MT+, which is active during the perception of MC, is also active during FFM (Vachon et al., 2009) and BM (Grossman et al., 2000). Therefore, a strong form of the motion processing hypothesis would predict impairment across all three tasks (see also Koldewyn et al., 2009). This is clearly not the case. However, it is important to note that proficient performance on the task does not necessarily indicate typical neural processing (see Brieber et al., 2010).

One explanation for the history of mixed results might be the heterogeneity of a symptom-defined disorder such as ASD. Two previous studies comment on outliers on this task (Milne et al., 2006; White et al., 2006), but in our sample we identified only one individual who could fit this profile. The range of findings for the MC task is difficult to disambiguate given the subtle differences in stimuli and procedure across tasks (see Kaiser & Schiffrar, 2009), alongside differences (age; IQ) in the samples tested. Of particular relevance, Annaz et al (2010) report a significant difficulty on the same MC task in children with an ASD (age range 5-12 years), although the ASD group had a lower verbal mental age than the non-ASD group. Indeed, many studies investigating MC do not match for verbal IQ (e.g. Pellicano et al., 2005; Milne et al., 2002; Milne et al., 2006).

A striking finding in our study was that performance on the three visual perception tasks was significantly correlated (even when partialling out IQ) in the ASD group but not in the non-

ASD group. We speculate that a shared cognitive process, such as attention (see Dakin & Frith, 2005), drove performance to a greater degree in the ASD than the non-ASD group. This explanation better predicts the highly variable findings across studies than a true perceptual difficulty with MC. MC deficits are also found in individuals with Williams syndrome (e.g. Atkinson et al., 1997), in children born prematurely (Taylor et al., 2009), and in children with dyslexia and reading impairments (e.g. Ridder et al., 2001; Cornelissen et al., 1998). Thus, difficulties in perceiving MC may also be a non-specific marker of neurodevelopmental disruption that is not systematically observed in ASD (see Braddick et al., 2003; Grinter et al., 2010).

The FFM task has been previously used in children with ASD, with a focus on the developmental trajectory (Annaz et al. 2010). Annaz et al. (2010) found that as with typically developing children, mental age predicted performance on the task in the ASD group, although the expected association with chronological age was not apparent and the ASD group performed more poorly overall. Another study, using an analogous task, found no impairment in a group of children and adults with ASD (de Jonge et al., 2007). Our findings indicate that perception of FFM in ASD is comparable to individuals without ASD by the time adolescence is reached.

A tail of ASD performers with poor biological motion

At the group level, adolescents with ASD were not impaired at processing BM compared to peers without an ASD. In contrast, Annaz et al (2010) found that children with ASD showed no evidence of improvement in the perception of BM with increasing chronological or mental age, unlike typically developing children. Our data suggest that by 14-16 years this atypical developmental course has been corrected in the majority of individuals with ASD. Previous data has produced inconsistent findings. However, there are fairly considerable differences in stimuli (e.g. use of noise dots) and tasks demands (e.g. direction judgement vs. recognising a 'person') across studies, which may in part explain the results. For example, it is suggested that direction judgement of a BM figure can be completed without conscious recognition of the biological

elements, and that the neural correlates are different when the focus of the task is oriented to recognising a 'person' (Vaina et al., 2001). It is notable that the majority of studies that find impairment in a group with ASD (Annaz et al., 2010; Blake et al., 2003; Kaiser et al., 2010; Koldewyn et al., 2009) use a child or adolescents sample and require identification of a person. Conversely, the majority of studies that find no group differences (Freitag et al., 2008; Herrington et al., 2007; Murphy et al., 2009; Saygin et al., 2010) use an adult population and require the identification of direction. However, the current study is significant in demonstrating that adolescents with ASD *can* perform well on BM tasks that focus on biological identification. Freitag et al (2008) report no group differences using a similar probe question but they did not add noise to their stimuli, meaning the task was less visually demanding. The current study is unusual in using a two forced choice paradigm and it might be that making a comparative judgement made the task more accessible for the group with ASD.

The data is clear in demonstrating that the processing of BM is not an area of difficulty for the majority of adolescents with ASD. However, our analysis identified a significant tail of participants with ASD who were extremely impaired at BM perception relative to their contemporaries. It is notable that over one third of the remaining individuals with ASD had a comparable profile of intellectual ability, so it would be incorrect to assume that the subgroup was entirely driven by low ability. Given the data provided by Annaz et al (2010), the tail of poor performers might represent those with a particularly sluggish maturation. The subgroup performed poorly on all three visual processing tasks and over a third fell into the poorly performing FFM subgroup. Therefore the data could reflect a difficulty in processing motion or form that is particularly vulnerable on the BM task, where the specific demands involve perceiving a biological form from motion cues. For example, it could be speculated that the social nature of the BM stimuli made it particularly challenging for the low functioning subgroup. Although it is also true that the BM task contains unique conceptual demands (i.e. understanding that a constellation of moving dots is representing a complex figure).

Neuroimaging data have suggested alternative perceptual and cognitive processes might be employed in ASD to enable adequate behavioural performance on visual processing tasks (Frietag et al., 2008; Herrington et al., 2007). For individuals who are unable to process these stimuli typically, those who are low functioning would be less equipped to exploit alternative processing strategies. Further work is required to ascertain why some lower functioning individuals with ASD can perform adequately on the BM task whilst others struggle.

Biological motion and animated triangles: indices of the superior temporal sulcus

The STS is thought to have a central and broad role in social cognition (e.g. Pelphrey & Carter, 2008) and is active during the processing of BM (see Allison et al., 2000) and the Frith-Happé animations (Castelli et al., 2002), two motion-based tasks that are relevant to social-cognition. This would predict that performance on the two tasks would be associated. Our data conform to this hypothesis, finding significant association between the ToM animations and the BM task for both groups of participants, even after accounting for full-scale IQ. There was weaker evidence for association with the GD animations, reflecting observation that neural activity in the STS during GD animations is intermediate between ToM animations and random animations (Castelli et al., 2002). The association was specific to the Frith-Happé animations and BM task; no associations were found with the other two visual perception tasks once the moderating effect of IQ had been accounted for. However, evidence for whether the STS is uniquely activated during biological motion compared to other motion processing tasks remains mixed (e.g. Braddick et al., 2000; Grossman et al., 2000; Pelphrey et al., 2003). Further, it is possible that a rudimentary aspect of visual processing, shared just by the two tasks, drove the association. Clearly, neuroimaging work is needed to confirm our hypothesis. Our participants with ASD showed a specific impairment on the Frith-Happé task for the ToM animations; they were not impaired when the interactions were GD. This finding replicates previous work that has demonstrated social cognitive difficulties for individuals with ASD on variants of this task (e.g. Abell et al., 2000; Castelli et al., 2002; Klin, 2000; Salter et al., 2008).

Previous studies have found preserved performance in ASD on BM tasks with ‘basic’ demands (e.g. recognising a ‘person’ vs. object; labelling the actions of PLD) but difficulty on emotion labelling of PLD (Moore et al., 1997; Hubert et al., 2007; Parron et al., 2008; although see Atkinson, 2009). The current data set is congruent with this finding i.e. preserved sensitivity to biological motion (at the group level) but impairment on a task in which higher-order information relating to behaviour, intentions and emotions must be extracted from moving agents. The ability to recognise BM does not mean that processing at the neural level is typical (see Freitag et al., 2008), and we speculate that atypical processing within the STS cannot be compensated for in more complex tasks. Related to this, during the processing of BM, the STS is active late in the processing hierarchy and relates to the complexity of the biological stimulus and the depth of processing required (Jastorff & Orban, 2009). Infants with ASD do not show the typical preferential looking for BM displays (Klin et al., 2009). Limited early-years engagement with these types of stimuli would no doubt impact the development of sophisticated processing mechanisms for interpreting moving biological stimuli.

Summary

In a large sample of adolescents with ASD, we found no evidence of impairment in the perception of MC, FFM or BM. This contrasts findings using the same tasks with a younger age group (Annaz et al 2010). One possibility is that the adolescents with ASD have developed compensatory strategies to aid performance or it may reflect the maturation of a delayed developmental process. Perhaps related to these issues, we found a tail of individuals with ASD who have exceptionally poor BM perception alongside relatively low intellectual ability. We have also established that perception of BM and the interpretation of the mental states of animate characters have a shared cognitive and perceptual route, which likely resides in the posterior STS. As both types of task activate a network of regions, functional imaging analysis is required to confirm this hypothesis.

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Table 1: Mean age, verbal IQ, performance IQ and full-scale IQ (SD in brackets) for the non-ASD and ASD groups

	n	M:F	Age	VIQ	PIQ	FSIQ
All						
Non-ASD	52	49:3	15;6 (6.1)	86.5 (20.5)	91.8 (22.1)	88.4 (22.6)
ASD	89	81:8	15;6 (5.5)	82.1 (17.7)	91.4 (18.1)	85.5 (17.6)
Subset who completed the animated triangles						
Non-ASD	50	48:2	15;6 (6.1)	87.7 (20.0)	93.0 (21.6)	89.7 (21.9)
ASD	79	71:8	15;6 (5.6)	84.4 (16.4)	93.2 (16.9)	87.6 (16.2)

Table 2: Mean threshold scores (standard deviation in brackets) for the three visual processing tasks

	Motion coherence	Form-from-motion	Biological motion
All			
Non-ASD	.25 (.20)	.27 (.11)	.35 (.12)
ASD	.19 (.14)	.29 (.15)	.39 (.14)
Subgroup who completed the animated triangles			
Non-ASD	.25 (.21)	.27 (.11)	.34 (.12)
ASD	.19 (.14)	.29 (.14)	.38 (.13)

Table 3: Mean scores (standard deviation in brackets) on the Frith-Happé animations

	Intentionality (0-5)	Appropriateness (0-2)	Length (0-4)
Theory of Mind animations			
Non-ASD	3.4 (.80)**	0.9 (.51)**	3.7 (.50)
ASD	2.9 (.89)	0.6 (.46)	3.4 (.86)
Goal-directed animations			
Non-ASD	2.7 (.66)	1.7 (.44)	3.5 (.86)*
ASD	2.6 (.77)	1.7 (.50)	3.2 (1.0)

** p < .01 * p < .05

Table 4: Correlations between motion coherence, form-from-motion, biological motion and fullscale IQ

Group	Correlation	Measures	MC	FFM	BM
ASD (n=93)	Full	FFM	.47***		
		BM	.54***	.47***	
		FSIQ	-.55***	-.42***	-.49***
	FSIQ partialled	FFM	.32*		
		BM	.38*	.22*	
Non-ASD (n=52)	Full	FFM	.10		
		BM	.23	.21	
		FSIQ	-.15	-.38**	-.60***
	FSIQ partialled	FFM	.05		
		BM	.18	-.02	

* $p < .05$ ** $p < .01$ *** $p < .001$

MC: motion coherence; FFM: form-from-motion; BM: biological motion; FSIQ: full-scale IQ

Table 5: Correlations between motion coherence, form-from-motion and biological motion, animated triangles and full-scale IQ

Group	Correlation	Measures	ToM	ToM	GD	GD
			Intentionality	Appropriateness	Intentionality	Appropriateness
ASD (n=79)	Full	MC	-.18	-.27*	-.01	-.14
		FFM	-.19	-.17	-.15	.08
		BM	-.34**	-.27*	-.13	-.26*
		FSIQ	.38**	.26*	.16	.18
	FSIQ partialled	MC	.01	-.17	.09	-.06
		FFM	-.05	-.07	-.09	.09
		BM	-.22*	-.18	-.07	-.21 ⁺
Non-ASD (n=50)	Full	MC	-.03	-.11	-.15	.17
		FFM	-.39**	-.36*	.03	-.30*
		BM	-.37**	-.58***	-.20	-.11
		FSIQ	.60***	.63***	.22	.29*
	FSIQ partialled	MC	.07	-.04	-.23	.22
		BM	-.19	-.15	.14	-.20
		BM	-.03	-.37**	-.09	-.20

⁺ p = .06 * p < .05 ** p < .01 *** p < .001

MC: motion coherences; FFM: form-from-motion; BM: biological motion; FSIQ: full-scale IQ

Figure 1: Examples of stimuli: (A) Motion coherences task; (B) Form-from-motion task; (C) Biological motion task. For illustrative purposes, signal elements are illustrated in red, while noise elements are white. The outline rectangles in (B) are also provided for illustrative purposes.

Figure 2: Box plots for the three visual processing tasks. The horizontal line indicates the cut-off of 1.65 standard deviations from the control mean.