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PAPER

Development of motion processing in children with autism

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Abstract

Recent findings suggest that children with autism may be impaired in the perception of biological motion from moving point-light displays. Some children with autism also have abnormally high motion coherence thresholds. In the current study we tested a group of children with autism and a group of typically developing children aged 5 to 12 years of age on several motion perception tasks, in order to establish the specificity of the biological motion deficit in relation to other visual discrimination skills. The first task required the recognition of biological from scrambled motion. Three quasi-psychophysical tasks then established individual thresholds for the detection of biological motion in dynamic noise, of motion coherence and of form-from-motion. Lastly, individual thresholds for a task of static perception – contour integration (Gabor displays) were also obtained. Compared to controls, children with autism were particularly impaired in processing biological motion in relation to any developmental measure (chronological or mental age). In contrast, there was some developmental overlap in ability to process other types of visual motion between typically developing children and the children with autism, and evidence of developmental change in both groups. Finally, Gabor display thresholds appeared to develop typically in children with autism.

Introduction

Several recent studies have demonstrated impairments in motion perception in individuals with autism. This corpus of work suggests abnormalities in different types of motion perception including: increased sensitivity thresholds for detecting coherent motion from random motion (Milne, Swettenham, Hansen, Campbell, Jeffries & Plaisted, 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Spencer & O'Brien, 2006; Spencer, O'Brien, Riggs, Braddick, Atkinson & Wattam-Bell, 2000); reduced sensitivity to second, but not first, order motion (Bertone, Mottron, Jelenic & Faubert, 2005b), and reduced sensitivity to biological motion (Blake, Turner, Smoski, Pozdol & Stone, 2003; Freitag, Konrad, Häberlen, Kleser, von Gontard, Reith,, Troje & Krick, 2008; see also Milne, Swettenham & Campbell, 2005, for a review). Perception of biological motion, which involves recognition of human motion reduced to a point-light display (PLD), has been shown to develop in early infancy (Fox & McDaniel, 1982) and is the focus of the current study.

Blake *et al*. (2003) reported that children with autism were less able to perceive biological motion than typically developing children when asked to identify a human point-light walker from scrambled dots with the same degree of movement. The authors linked this impairment to severity of autism. Using fMRI, Herrington *et al*. (Herrington, Baron-Cohen, Wheelwright, Singh, Bullmore, Brammer & Williams, 2007) measured brain activation in individuals with autism spectrum disorder (ASD) while observing biological motion stimuli. The authors reported reduced activation relative to control participants in inferior, middle and superior temporal regions, including V5/MT. Atypical neural activation was also reported in Freitag and colleagues' (2008) study of 15 adolescences with autism who had IQ within a normal range.

Several studies, however, have shown that individuals with autism are able to name simple actions such as kicking and digging depicted by PLD (Hubert, Wicker, Moore, Monfardini, Duverger, Da Fonseca & Deruelle, 2007; Moore, Hobson & Lee, 1997; Parron, Da Fonseca, Santos, Moore, Monfardini & Deruelle, 2008). In these studies, exposure time was longer (5 seconds) than in Blake *et al*. (2003) (1 second), and verbal responses were the dependent variable. Participants were impaired relative to controls at naming emotions depicted by

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point-light movement. The authors argued that the impairment in biological motion perception is specific to displays depicting emotion. Their evidence suggests that participants with autism can name simple biological motion displays if given enough time, but this does not rule out the possibility that they are less *sensitive* to biological motion stimuli.

There is also evidence that children with autism are impaired on other motion perception tasks. A number of studies have reported that some individuals with autism are less sensitive to coherent motion and/or to texture defined motion stimuli (Bertone, Mottrom, Jelenic & Faubert, 2003; Milne *et al*., 2002; Pellicano *et al*., 2005; Spencer & O'Brien, 2006; Spencer *et al*., 2000). The existence of deficits in more than one type of motion task has led to the suggestion that there may be a single underlying cause accounting for a motion perception deficit. For example, a number of authors have argued that a general vulnerability of the dorsal cortical processing stream underlies atypical performance on motion perception tasks (Blake *et al*., 2003; Milne *et al*., 2002; Spencer *et al.,* 2000), whilst Bertone and colleagues (Bertone, Mottron & Faubert, 2005a) have suggested that a general abnormality in neurointegrative mechanisms within visual cortex results in a deficit in feature integration of complex stimuli (i.e. stimuli that require processing beyond the level of V1; see also Grice, Spratling, Karmiloff-Smith, Halit, Csibra, de Haan & Johnson, 2001) which would include biological motion, global motion and texture defined motion.

One way forward, then, is to test a group of children with autism on several motion perception tasks to establish the pattern of performance. A dissociated pattern of performance has been reported in children with Williams Syndrome (WS). Reiss and colleagues reported that individuals with WS are impaired in their ability to perceive form-from-motion but not biological motion (Reiss, Hoffman & Landau, 2005). The authors propose that the *relatively* typical development of biological motion perception in WS could be explained by their tendency to be highly interested in social stimuli.

In the current experiments, we tested a group of children with autism on several different motion perception tasks and on a static contour integration task (Kovacs, Polat, Norcia, Pennefather & Chandna, 2000). In the first experiment we attempted to replicate Blake *et al*.'s (2003) finding by presenting children with brief displays of point-light biological motion and point-light scrambled motion, using a signal detection measure of discrimination ability. Also, similarly to Blake *et al.* (2003), correlation between severity of autism and performance was measured using Childhood Autism Rating Scale (CARS) (Schopler, Reichler & Renner, 1986). In the second experiment we used a quasi-psychophysical procedure similar to previous studies (Friere, Lewis, Maurer & Blake, 2006; Jordan, Reiss, Hoffman & Landau, 2002; Reiss *et al*., 2005). The motion stimuli were embedded in noise, and signal-to-noise ratio was gradually increased and decreased using a staircase procedure to establish the threshold at which the stimuli could be reliably perceived. Thresholds for perception of (1) biological motion, (2) coherent motion, and (3) form-from-motion were assessed in this way (Experiment 2).

Thus, in Experiments 1 and 2, we tested biological motion processing in two ways. This allows more reliable inferences concerning sources of any deficit than if a single test were used. For example, in Experiment 1 it may be possible to distinguish a real from a scrambled PLD on the basis of local detail. However, a threshold test (Experiment 2) is unlikely to be affected by this, since dynamic noise limits the ability to discriminate biological motion from local correspondences. Finally, in Experiment 3, we tested form perception from a static display, using the contour integration task described by Kovacs and colleagues (Kovacs, Kozma, Feher & Benedek, 1999). This uses sinusoidal luminance patterns, or Gabor displays. The basic processes involved in discriminating Gabor displays from noise are likely to reflect local integration activity in occipital area V1. These are thought to be developing typically in autism (Bertone *et al*., 2003; Kemner, Lamme, Kovacs & van Engeland, 2007).

Based on the studies mentioned here, we predicted that biological motion would be impaired in the autism group, while our predictions concerning thresholds for other motion tasks (coherent motion and form from motion) are open. We predicted that thresholds for the detection of visual form from Gabor patches would be similar in the autism and control groups.

The use of cross-sectional developmental trajectories

The majority of studies examining perceptual abilities in children with autism have used cross-sectional designs, matching children from the disorder group with TD controls based on chronological or mental age. If children with autism perform significantly worse than the control group, they are often described as *impaired* (and we have used this terminology, too). However, such studies give little sense of how task performance develops with age, or other developmental markers that are particularly important when studying a developmental disorder such as autism. Although cross-sectional studies cannot replace longitudinal studies, they can be used to *indicate* developmental change, since they allow trajectories to be mapped from individuals at different developmental stages (Thomas, Annaz, Ansari, Scerif, Jarrold & Karmiloff-Smith, 2009). The cross-sectional method we used begins by constructing a trajectory for each task across TD individuals at different ages. The trajectory of the autism group is then compared to this reference in a number of ways. A trajectory that links changes in performance to chronological age establishes whether the autism group shows any impairment. Trajectories linking performance to measures of mental age indicate whether the behavioural deficit is in line with the developmental

state of other aspects of the cognitive system. In the current study we used this method to assess the development of motion perception in children with autism aged 5 to 12 years.

Method

Participants

Twenty-three children with autism and 34 typically developing children participated in the current study. (See Table 1 for group details.) All the children in the group with autism met established criteria for autism, as specified in DSM-IV (American Psychiatric Association, 2000), with diagnosis confirmed with ADOS (Lord, Rutter, DiLavore & Risi, 1999). None of the children with autism had received any other diagnosis. All participants had normal or corrected-to-normal vision. The experimental protocol was approved by the Ethics Committee, University College London, and both parental informed consent and the child's assent were obtained before participation. In order to obtain verbal and non-verbal mental age scores, children from both groups were assessed on a number of standardized tests including the British Picture Vocabulary Scale II (Dunn, Dunn, Whetton & Burley, 1997) and the Pattern Construction subtest from the British Ability Scale II (Elliott, Smith & McCulloch 1997). There was no difference between the groups on CA and PC ($p > .05$), but there was a significant group difference on BPVS [$F(1, 55) = 5.55$, $p = .023$]. Also, severity of autism scores using CARS scale is reported in Table 1. There was no correlation between scores obtained on CARS and chronological age ($p > .05$). As a further check on the possibility that severity of the disorder varied across the sample, one-way ANOVA comparing younger (5–8 years) and older (8.1–12.2 years) for CARS scores revealed no differences in severity of the disorder between the age groups [$F(1, 21) = 23.74$, $p = .114$].

Apparatus

Stimuli were presented on an HP laptop with a 15-inch flat-panel LCD screen (1024 × 768 pixel resolution; 60 Hz frame rate). Custom software, using Microsoft Visual Basic, was used to control the display and responses. Viewing distance was approximately 40 cm.

Experiment 1: Perception of biological motion (normal vs. scrambled)

Stimuli

Point-light displays (Johansson, 1973) were created using a Markerless motion-capture method (Shipley & Brumberg, 2003) and were composed of 13 signal dots attached to the joints of an invisible human figure (head, two shoulders, two elbows, two hands, two hips, two knees and two feet). The figure was seen in profile (approximately 7.8° visual angle in height) and remained in the centre of the panel as if walking on the spot. Four further figures were created (running, throwing, kicking and star-jumping) resulting in a set of five PLD animations (see Figure 1A). Corresponding out-of-phase scrambled stimuli were created for each of the five actions by taking the trajectory of each dot and playing them temporally out of phase with each other (hence controlling for display density and overall movement). Each animation was presented as white dots on a black panel (17.1° × 17.1° visual angle). The duration of each trial was 1 second, followed by an inter-stimuli fixation cross.

Procedure

The task began with 10 practice trials (five PLD and five scrambled trials, presented randomly). The first five trials were presented on the screen until a response was made and the second five trials were presented for 1 second duration. In the practice session, each child was told that during the game he/she would sometimes see dots that '*moved like a person*' and sometimes dots that would 'moved *in a funny way and not really like a person*'. The keyboard of the computer was covered with black card so that only the z and m keys were visible. These keys were covered by Y and N stickers, respectively. Participants were told to press 'Y' if the dots were moving like a person and to press 'N' if they were not.

Table 1. *Test results per group. TD = typically developing, ASD = Autism group, CA = chronological age, BPVS = British Picture Vocabulary Scale (Dunn, et al., 1996), PC = pattern construction subtest of the British Abilities Scale II (Elliot, et al., 1987), CARS = Childhood Autism Rating Scale (Schopler et al., 1997).*

Group (sample size)	Statistic	CA (yrs: months)	BPVS-VMA (age equivalent yrs:months)	PC – NVMA (age equivalent yrs:months)	CARS
TD (n=34)	Mean	8:3	8:5	8:3	—
	S.D.	2:3	2:3	2:1	—
	Range	4:6–12:3	4:11–13:0	5:7–13:9	—
ASD (n=23)	Mean	8:10	7:2 *	8:11	36
	S.D.	1:10	1:8	3:1	4.7
	Range	5:0–12:2	4:4–10:1	4:10–15:3	30

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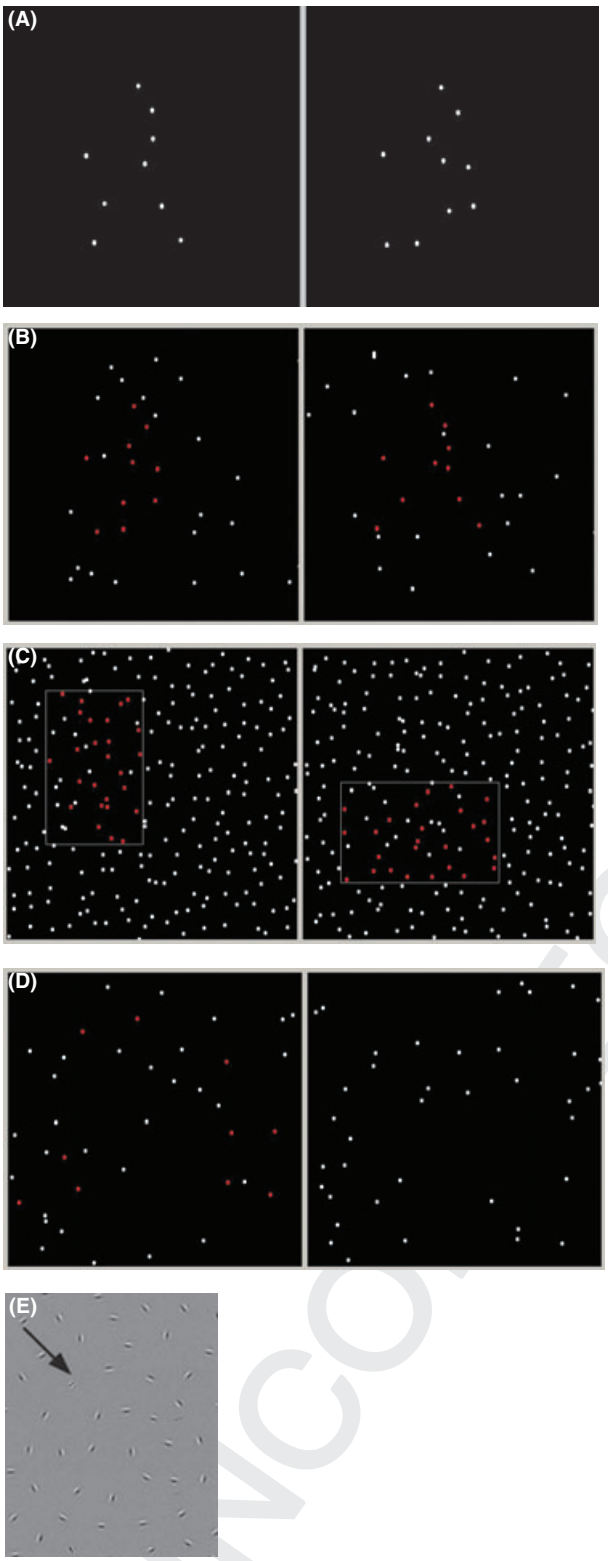

Figure 1 *Examples of stimuli (A) biological motion perception task; (B) biological motion detection task; (C) motion coherence, and (D) form-from-motion. For illustration purposes, signal elements, in examples B–D, are indicated in red, while noise elements are coloured white. All elements appeared white signals on a black background and (E) the 12-element Gabor defined contours embedded in backgrounds of different noise density with a ratio of background element spacing to contour element spacing (D) of 0.9.*

Once the child was familiar with the procedure, the 40 experimental trials (each with a duration of 1 second) were then presented in random order with constraints such that no more than two of the same action or same phase could appear consecutively. The experimenter controlled the progression of the task by clicking a button to initiate each subsequent trial

Experiment 2: Sensitivity to motion tasks

These tasks examined whether children with autism have altered sensitivity to detect different types of motion. Three tasks were developed based on a procedure used by Reiss *et al.* (2005): biological motion, form-from-motion and motion coherence. See examples of stimuli in Figure 1(B–D).

General procedure

Participants completed all motion tasks in separate blocks presented in counterbalanced order. Each child was tested separately in a quiet room. For each task, participants were asked to indicate which panel contained the target stimuli, by pressing a button underneath the relevant panel. Perceptual thresholds were established using a two-down/one-up adaptive staircase rule on each of the motion tasks. Three noise dots were added to the target and adjacent distractor panel after every two consecutive successful trials. However, if the child responded incorrectly on a trial then six noise dots were subtracted. The task continued until seven reversals had taken place (i.e. 7 correct followed by incorrect trials). The average signal-to-noise ratio (signal/signal + noise) of the seven reversals was calculated to establish the threshold.

Stimuli

Biological motion task

This task was designed to establish thresholds for the detection of PLD in noise. In this task, two displays were presented side by side. One contained a display of a PLD walking on the spot, in profile view. The other display comprised matched but scrambled elements as described above. The first trial contained only signal elements (PLD alone). Groups of three distractor dots were added or removed on subsequent trials depending on accuracy of response. Participants pressed a button which corresponded to a panel where they could see '*dots that look like a person walking*'. The staircase procedure described above was applied to determine the threshold.

Motion coherence task

This task was designed to establish motion coherence thresholds for each respondent. Two black panels were

displayed on the screen, each containing randomly positioned signal elements. In one of the panels, signal elements moved together in the same direction (3.21°/s) while, in the other panel, noise elements moved randomly to new locations within the panel. Respondents were required to identify the panel comprising the coherent display. Within each display, each signal element had a lifespan of one frame (limited lifetime technique: Newsome & Paré, 1988) in order to ensure that one particular element could not be followed through a trial. Participants were asked to detect which set of dots were moving in the same way '*like swimming fish*'. Two consecutive correct responses led to the addition of three noise elements to both panels and an incorrect response led to the removal of six noise elements.

Form-from-motion task

This task was designed to establish form-from-motion thresholds for each respondent. In each of two black panels signal elements were arranged into a rectangular figure and surrounded by background noise elements. The figure and background elements moved coherently in opposite directions (3.21°/s). Noise elements (with random motion) were present in both the figure and the background. In one panel the figure was horizontal and in the other the figure was vertical. The task was to identify the panel containing the vertical rectangle. Participants were told that there was a rectangle hidden inside each panel on the screen. A cardboard rectangle of similar size and shape was presented to the child to ensure that they understood what shape they were looking for. The cardboard shape was then rotated to a vertical position and the participant was directed to look for the '*rectangle that is standing up on its end*' and to press the button underneath that panel. The overall density of dots was constant throughout the task and difficulty was manipulated by converting signal elements to noise elements. Two consecutive correct responses led to the conversion of three signal elements into noise elements and an incorrect answer changed six noise elements back to signal elements.

Experiment 3: Static contour integration task

Stimuli

The stimuli comprised colinearly aligned Gabor signals (contour) displayed against randomly oriented and positioned Gabor signals (noise), as created by Kovacs and Julesz (1993). Spacing of contour and noise elements was controlled independently. At low signal-to-noise ratios, background elements intruded between contour elements, but orientational alignment was avoided. A different random shape and background were computed for each card. The difficulty level of each card was determined by the relative density of noise elements and expressed as a ratio of average noise spacing over contour spacing (D). Absolute contour spacing is expressed in Gabor wavelength units (λ). The strength of spatial interactions subserving contour integration in an individual is indicated by the value of D at their threshold. An example of the contour-integration stimuli is shown in Figure 1 (see Kovacs *et al*., 1999; Kovacs *et al*., 2000, for details).

Procedure

Initially, each participant was asked to draw a circle to ascertain that he/she could recognize a circle when asked. If this was done correctly, the participant was presented with one of the two sets of A4 cards at approximately 40 cm distance. The participant's task was to identify the location of the contour by tracing its path with their finger. Each child was presented with one practice trial to ensure that s/he understood the task procedure. The cards were presented in increasing order of difficulty and children were given a 6 seconds limit to given an answer. D varied between 0.5 and 1.2 in steps of 0.05, resulting in 15 cards in the set. A simple staircase procedure was used in which threshold was identified by the last correctly identified card.

Results

The data were analysed as follows: (i) We first examined developmental trajectories for each group for each task. Each developmental trajectory was modelled by a linear function relating individuals' d-prime (d') scores (Experiment 1) or thresholds (Experiments 2 and 3) to chronological age; (ii) if both groups showed a reliable linear relationship between the dependent variable and age, this was followed by a direct comparison between the groups (using cross-sectional ANCOVA with CA or MA as covariant) to determine whether the performance of the children with autism differs in terms of onset (the level of performance at the point at which measurement began) and rate of development; (iii) finally, performance values were plotted against mental ages from the British Picture Vocabulary Scale II (BPVS) and Pattern Construction subtest from the British Ability Scale II (PC) tasks to explore whether performance was in line with a given standardized measure (see Thomas *et al*., 2009, for a similar approach). d' values (Experiment 1) measure perceptual sensitivity independent of bias, in forced choice paradigms (Macmillan & Creelman, 1991). d' value of 0.05 suggests low (chance-level) sensitivity.

Experiment 1: Identification of biological motion (normal vs. scrambled)

d' values were calculated for each child. The average d' values for the TD and autism groups were 2.2 and 1.0,

respectively. Figure 2a shows *d′* scores for every participant from both groups. Initial linear regressions revealed that *d′* values increased reliably with chronological age in the TD children [$F(1, 33) = 29.25$, $p < .001$] but not in the autism group [$F(1, 22) = 0.05$, $p = .83$]. The lack of a reliable relationship between *d′* and chronological age in the autism group is ambiguous. It may either mean that there is no systematic relationship between these variables, that is, their performance could be either random with respect to age, or *d′* could be constant with age. However, in neither case can age predict variability in *d′*.

Next, we compared the trajectories for performance at onset (i.e. at the earliest age that both groups were tested, 60 months) and the rate of change in performance relative to CA. There was no overall effect of group [$F(1, 53) = 0.55$, $p = .46$, $\eta_p^2 = 0.10$], indicating that the groups did not differ in performance at onset, reflecting overlap in performance at the earliest age tested. However, the Group by CA interaction [$F(1, 53) = 15.81$, $p < .001$, $\eta_p^2 = 0.23$] indicated that the groups differed in the rate of increase in performance with age. *d′* increased with age in the TD group but not in the group with autism.

We then examined whether there was a reliable relationship between performance on the task and mental age measures to see whether the behavioural deficit is in line with the developmental state of other aspects of the cognitive system (see Figure 2b and c). As expected, in the TD children (since mental age is in line with CA) *d′* increased systematically with verbal mental age (VMA) [$F(1, 33) = 15.94$, $p < .001$] and non-verbal mental age (NVMA) [$F(1, 33) = 22.26$, $p < .001$]. In contrast, the performance of children with autism was flat and *d′* remained constant with increasing verbal mental age [$F(1, 22) = 0.20$, $p = .66$] and non-verbal mental age [$F(1, 22) = 0.26$, $p = .62$].

A comparison of the VMA trajectories also revealed no difference between the groups at onset [$F(1, 53) = 0.07$, $p = .80$, $\eta_p^2 = 0.11$] and a significant Group by VMA interaction [$F(1, 53) = 4.61$, $p = .04$, $\eta_p^2 = 0.32$], indicating that the groups differed in the rate of development relative to VMA on this task. Similarly, a comparison of the NVMA trajectories revealed no significant group difference [$F(1, 53) = 0.01$, $p = .93$, $\eta_p^2 = 0.10$], indicating that the groups did not differ at onset, and a significant Group by NVMA interaction [$F(1, 53) = 15.81$, $p < .001$, $\eta_p^2 = 0.23$], again demonstrating that the groups differed in the rate of development relative to NVMA.

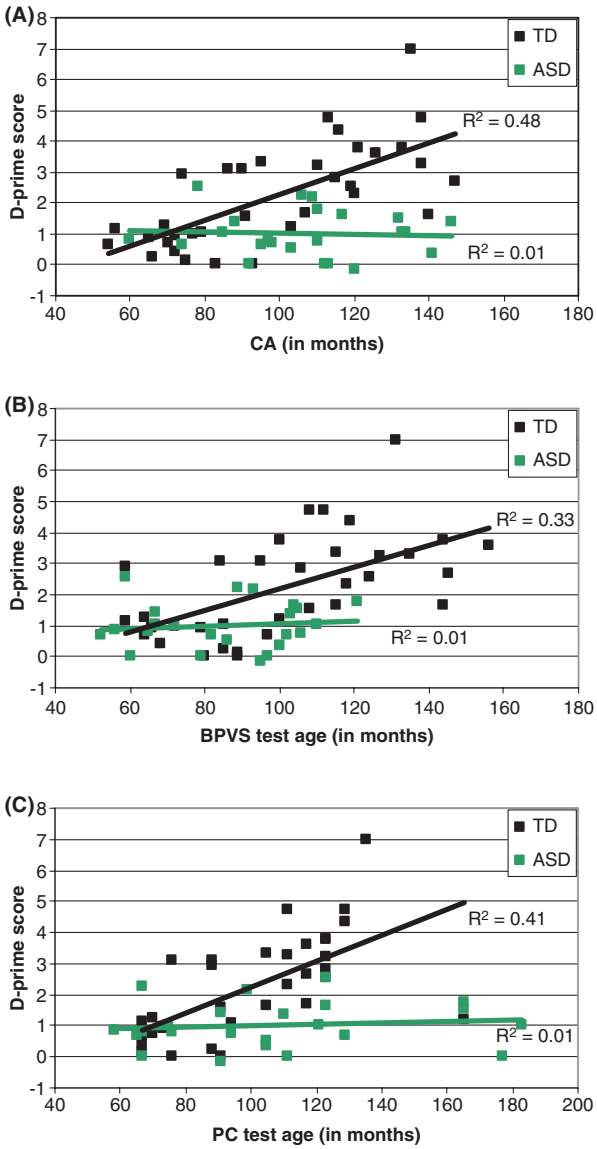

Figure 2 *Developmental trajectories for the autism and control group (expressed in d′ values) on recognition of biological motion PLD task plotted according to: (A) chronological age of the participants (CA in months); (B) BPVS test age equivalent (age in months) and (C) Pattern Construction test age equivalent scores (age in months). R^2 values indicate the proportion of variance explained by each trajectory.*

Experiment 2: Perceptual sensitivity to motion embedded in noise

Coherence thresholds for each child were computed as the mean of the threshold levels corresponding to the participant's last five staircase reversals in a given motion task.

A. Detection of biological motion

Initial linear regressions revealed that thresholds decreased reliably with CA in the TD children [$F(1, 33) = 19.82$, $p < .001$]. In contrast, threshold remained constant with increasing CA in the children with autism [$F(1, 22) = 1.86$, $p = .19$]. As depicted in Figure 3a, comparison of both trajectories showed no overall effect of group [$F(1, 53) = 0.75$, $p = .39$, $\eta_p^2 = 0.01$], indicating that the groups did not differ in performance at onset. However, there was a significant Group by CA interaction [$F(1, 53) = 4.88$, $p = .03$, $\eta_p^2 = 0.08$], indicating that TD children's thresholds fell as they got older, while this was not the case for children with autism.

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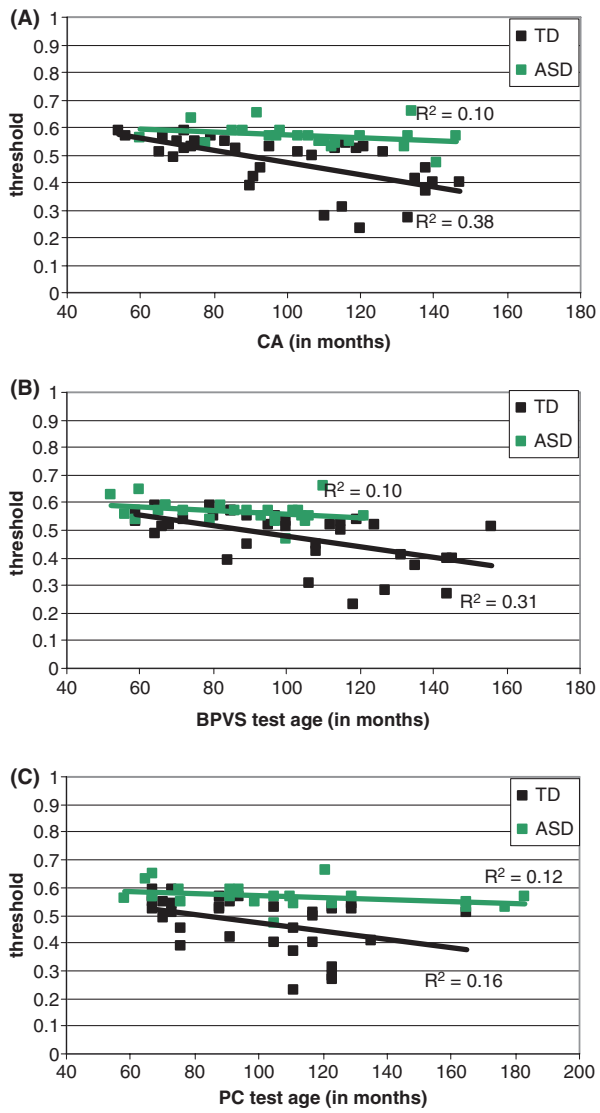

Figure 3 *Developmental trajectories for the autism and control group (expressed in threshold values) on the identification of biological motion PLD task plotted according to: (A) chronological age of the participants (CA in months); (B) BPVS test age equivalent (age in months) and (C) Pattern Construction test age equivalent scores (age in months). R^2 values indicate the proportion of variance explained by each trajectory.*

Figure 3(b and c) shows the thresholds for each individual plotted against VMA and NVMA on each motion task. For the TD children, linear regressions revealed that threshold decreased with increasing verbal [$F(1, 33) = 14.43$, $p < .001$] and non-verbal mental age [$F(1, 33) = 5.91$, $p = .02$]. In contrast, the performance of children in the autism group was constant with verbal [$F(1, 22) = 2.41$, $p = .14$] and non-verbal mental ages [$F(1, 22) = 2.84$, $p = .11$].

A direct comparison of the VMA trajectories revealed no effect of group [$F(1, 53) = 0.68$, $p = .42$, $\eta_p^2 = 0.13$], indicating no difference between the groups at the earliest VMA tested, and no significant Group by VMA interaction [$F(1, 53) = 2.44$, $p = .13$, $\eta_p^2 = 0.21$], indicating that the groups did not differ significantly in the rate of development relative to VMA on this task. Interestingly, the TD group showed a greater variability in performance compared to the autism group, and the group by performance interactions (comparisons of rate of development) may have fallen short of significance because of the unequal variance in the two groups. Similarly, comparison of the NVMA trajectories revealed no difference between the groups in threshold at the earliest NVMA tested [$F(1, 53) = 3.52$, $p = .07$, $\eta_p^2 = 0.33$], and no significant Group by NVMA interaction [$F(1, 53) = 2.89$, $p = .09$, $\eta_p^2 = 0.18$].

B. Sensitivity to motion coherence

As depicted in Figure 4a, linear regressions of thresholds decreased reliably with CA in the TD group [$F(1, 33) = 8.52$, $p = .006$]. In contrast, there was no reliable relationship between threshold and CA in the autism group [$F(1, 22) = 0.01$, $p = .77$]. Due to a lack of systematic relationship between age and the performance scores in the autism group, the developmental trajectory could not be constructed. We therefore carried out a *t*-test which revealed a significant difference between the groups [$t(55) = 3.53$, $p < .001$].

Figure 4b and c shows thresholds plotted against verbal and non-verbal mental ages. For the TD children, linear regressions revealed that threshold decreased with increasing verbal [$F(1, 33) = 5.39$, $p = .03$] and non-verbal mental ages [$F(1, 33) = 8.05$, $p = .01$]. However, children with autism showed a non-systematic relationship between threshold and verbal [$F(1, 22) = 0.85$, $p = .37$] and non-verbal mental ages [$F(1, 22) = 3.77$, $p = .07$].

C. Sensitivity to form-from-motion

Figure 5a shows that linear regressions of threshold scores decreased reliably with age in the TD group [$F(1, 33) = 7.61$, $p = .01$]. In contrast, there was no reliable relationship between threshold and CA in the autism group [$F(1, 23) = 2.74$, $p = .11$]. Again, a *t*-test was performed and showed a significant difference between the groups [$t(55) = 4.80$, $p < .001$]. Furthermore, for the TD children, threshold values decreased with increasing verbal [$F(1, 33) = 8.70$, $p = .01$] and non-verbal mental age [$F(1, 33) = 14.06$, $p = .001$]. The autism group also showed a reliable decrease in threshold with increasing verbal [$F(1, 22) = 0.19$, $p = .04$] and non-verbal mental ages [$F(1, 22) = 15.2$, $p = .001$]. A comparison of the NVMA trajectories revealed a significant effect of group [$F(1, 53) = 29.57$, $p < .001$], indicating that at the lowest NVMA, the autism group started with thresholds lower than the TD group predicted by NVMA. There was no significant Group by NVMA interaction [$F(1, 55) = 2.06$, $p = .16$], indicating that the groups did not differ significantly in the rate of development relative to NVMA on this task. A similar pattern was found when comparing the groups' trajectories of performance relative to

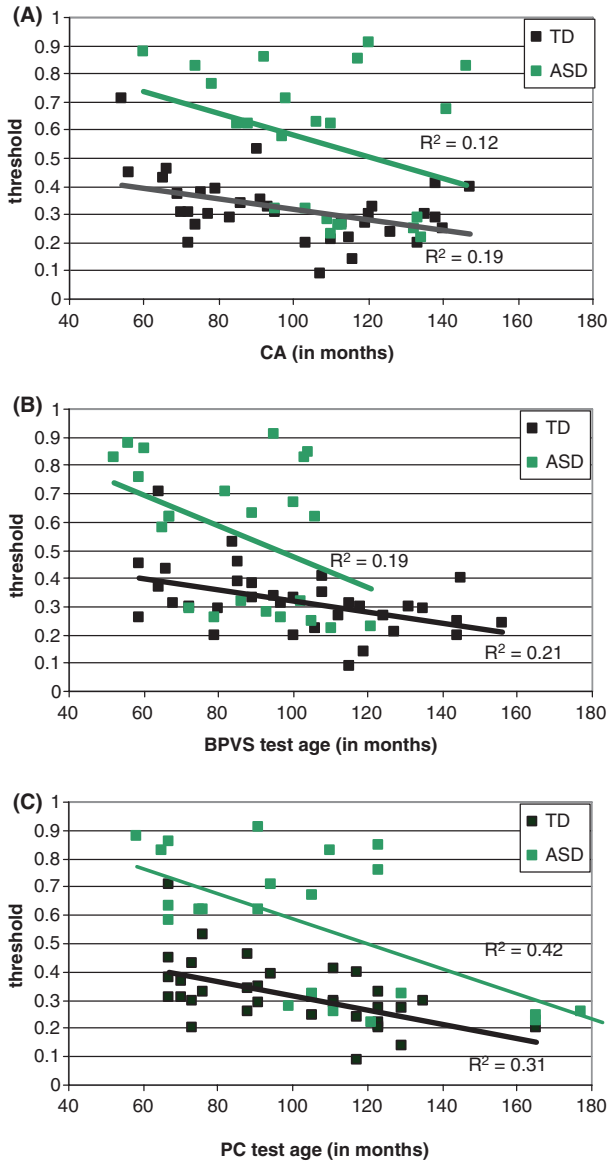

Figure 4 *Developmental trajectories for the autism and control group (expressed in threshold values) on the motion coherence PLD task plotted according to: (A) chronological age of the participants (CA in months); (B) BPVS test age equivalent (age in months) and (C) Pattern Construction test age equivalent scores (age in months). R^2 values indicate the proportion of variance explained by each trajectory.*

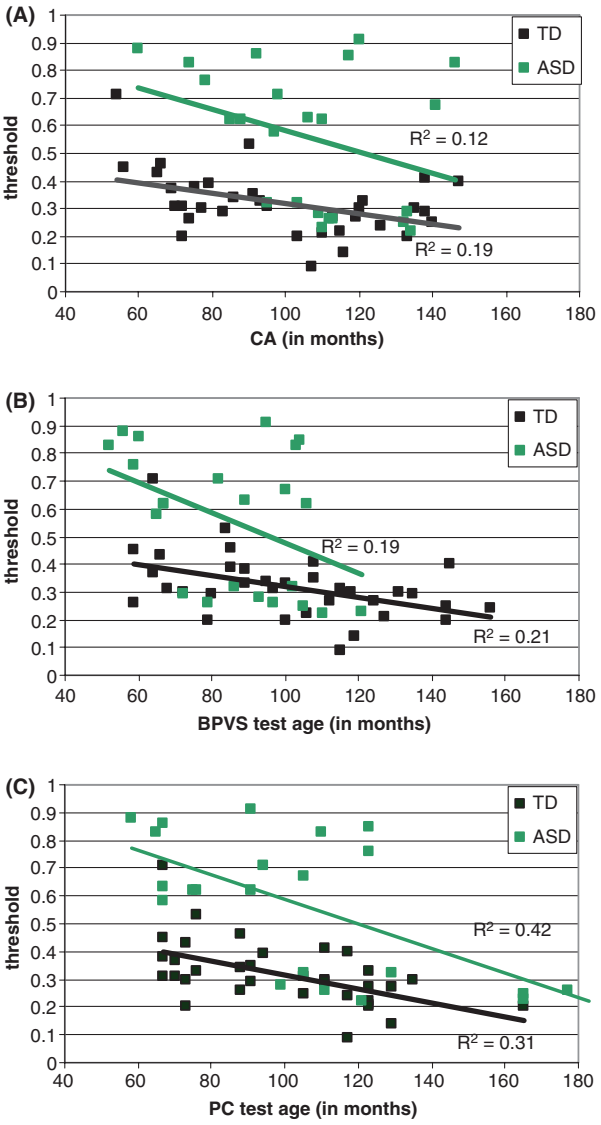

Figure 5 *Developmental trajectories for the autism and control group (expressed in threshold values) on the form-from-motion PLD task plotted according to: (A) chronological age of the participants (CA in months); (B) BPVS test age equivalent (age in months) and (C) Pattern Construction test age equivalent scores (age in months). R^2 values indicate the proportion of variance explained by each trajectory.*

VMA. The autism group showed delayed onset [$F(1, 55) = 14.29$, $p = .001$], and there was no difference in the rate of development relative to VMA [$F(1, 55) = 2.88$, $p = .09$]. (See Figure 5b and c.)

Cross-task comparison

In a further analysis we compared the relative levels of performance across the three motion tasks. Because of the inherent problem in comparing raw performance scores across different tasks, we standardized ASD scores in relation to normative functions for the TD group. First, individual data points from the TD sample were used to derive normative functions for the development of performance on each task with chronological and mental age. These functions were then used to derive normative *z*-scores for the ASD group which indicate the degree to which performance differs from TD developmental trajectory. Such *z*-scores were then used to compare performance across the tasks for the ASD group (see Jarrold, Baddeley & Phillips, 2007, for similar approach). Figure 6(a and b) depicts performance on each task using *z*-score standardization. One-way ANOVA with three task factors (biological motion, form-from-motion and motion coherence) revealed a significant main effect of task on the CA [$F(1, 22) = 5.28$; $p = .031$] and mental ages

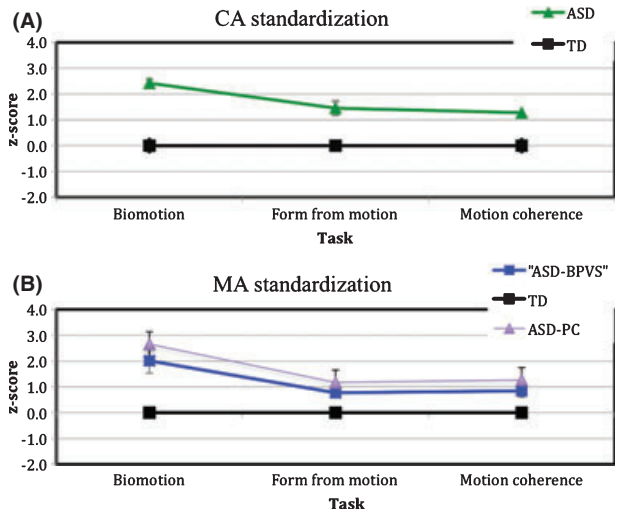

Figure 6 *Cross-task performance for the autism group expressed in z-scores plotted according to: (A) chronological age of the participants; (B) BPVS test age equivalent (age in months) and (C) Pattern Construction test age equivalent scores (age in months).*

standardizations [BPVS: $F(1, 22) = 7.12$; $p = .014$; PC: $F(1, 22) = 9.63$; $p = .005$)]. Further analyses revealed a significantly poorer performance (higher *z*-scores) relative to the TD group, on the biological motion task in comparison to the other two tasks ($p < .05$) and no difference between the form-from-motion and motion coherence tasks ($p >. 05$) on either CA or MA standardizations.

A Pearson correlation on the data for the children with autism addressed the relationship between performance on the three motion perception tasks. The correlation between motion coherence and form-from-motion was found to be significant ($r = .49$, $p < .05$), while the correlation between biological motion and either motion coherence or form-from-motion were statistically non-significant ($r = .16$, $p = .46$; $r = .15$, $p = .50$, respectively). The relationship between performance on the motion coherence and form-from-motion remained statistically significant even after chronological age and verbal mental age were taken into account ($r = .51$, $p < .05$; $r = .41$, $p < .05$, respectively), but was not statistically significant when non-verbal mental age was partialled out ($r = .35$, $p = .11$).

Lastly, a more descriptive approach was taken to inspect individual data points on all motion threshold tasks which revealed that the thresholds for some children with autism were within the TD children's developmental trajectory (95% confidence interval), and others had higher thresholds outside this range. As shown in Table 2, children with high thresholds on one task can be within the normal range on another, thus revealing considerable heterogeneity of individual performance across the tasks. We also computed the correlation between severity of autism, as indexed by CARS scores, and performance scores on the tasks. No correlations reached significance; however, note that form-from-motion scores approached significance level ($r = .401$, $p = .058$).

Table 2. *Individual patterns of performance on each of the motion tasks for children in the autism group. Thresholds within the normal trajectory (95 confidence intervals) are depicted with + symbol and ↑ when performance was above normal trajectory (95 confidence intervals).*

No	CA (months)	CARS	Biological motion d'	Biological motion threshold	Form-from-motion threshold	Motion coherence threshold
1	60	33	+	+		
2	74	35				
3	78	33	↑	+		
4	85	38.5				
5	88	35	+			↑
6	92	39				
7	95	38			+	↑
8	97	38				
9	98	47				
10	103	32			+	
11	106	40	+			
12	109	34			↑	+
13	110	30			↑	
14	110	31				↑
15	112	40.5			↑	+
16	113	34			+	
17	117	47.5				
18	120	38.5				
19	132	30			+	
20	133	31			+	↑
21	134	34			+	
22	141	33				
23	146	35				
%			**17**	**8**	**39**	**26**

Experiment 3: Sensitivity to contour integration

As depicted in Figure 7, both groups performed at a similar level on the contour integration task and there was a reliable increase in performance with age in both groups [TD: $F(1, 33) = 9.6$, $p = .01$; autism: $F(1, 22) = 10.16$, $p = .004$]. There were no differences between the groups in onset [$F(1, 56) = 0.27$; $p = .61$] or in rate of development (increasing threshold with CA) [$F(1, 53) = 1.22$, $p = .27$].

For the TD group, threshold decreased with increasing verbal [$F(1, 33) = 8.70$, $p = .01$] and non-verbal mental age [$F(1, 33) = 14.06$, $p = .001$]. For the autism group, the relationship between threshold and mental age approached significance [VMA: $F(1, 22) = 3.75$, $p = .06$; NVMA: $F(1, 22) = 3.8$, $p = .06$]. Further analysis showed no difference between the groups at onset, relative to mental age [VMA: $F(1, 53) = 1.65$, $p = .20$; NVMA: $F(1, 53) = 1.17$, $p = .29$], and no difference in rate of development according to mental age [VMA: $F(1, 53) = 0.12$, $p = .73$; NVMA: $F(1, 53) = 0.18$, $p = .68$].

COLOUR

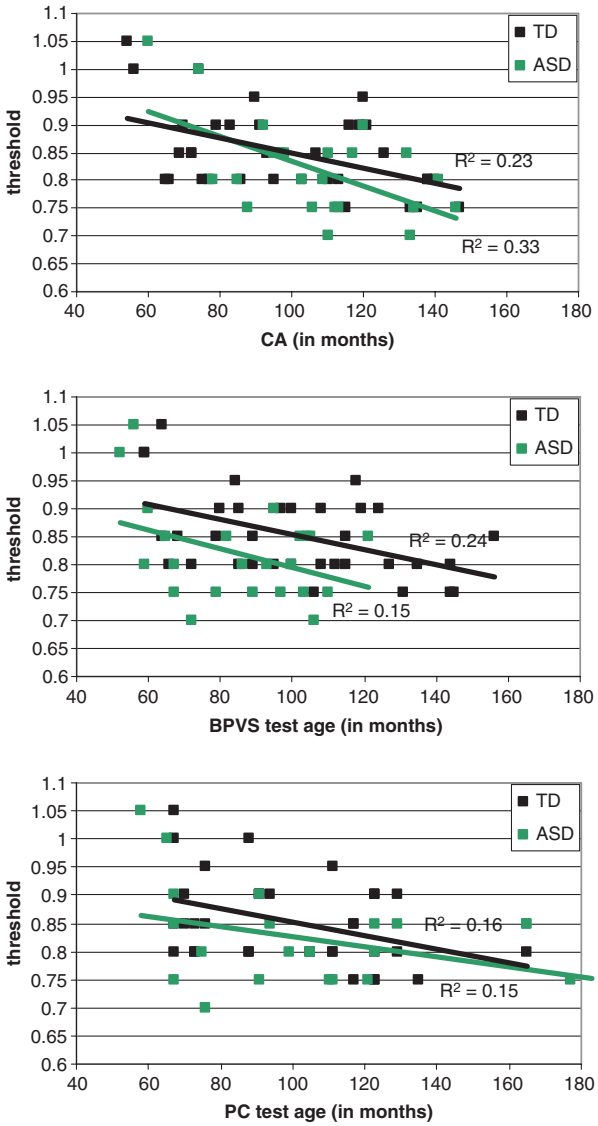

Figure 7 *Gabor task thresholds. Developmental trajectories for the autism and control group (expressed in D values) plotted according to: (A) chronological age of the participants (CA in months); (B) BPVS test age equivalent (age in months) and (C) Pattern Construction test age equivalent scores (age in months). R^2 values indicate the proportion of variance explained by each trajectory.*

Discussion

Several recent studies have suggested that the perception of biological motion and coherent global motion may be atypical in individuals with autism relative to MA-matched-controls (Blake *et al.*, 2003; Milne *et al.*, 2002, Pellicano *et al.*, 2005 Spencer *et al.*, 2000). However, it is not clear how universal these abnormalities are or whether a specific type of motion perception is more commonly affected in autism. It is also not known whether impairment on one motion task necessarily implies impairments on others, suggesting a common cause or a developmental association. In this study, we tested a group of children with autism and a group of typically developing children on a range of different motion processing tasks (biological motion, motion coherence, and form-from-motion) and one static contour integration task. We took a developmental approach, testing children across the age range from 5 to 12 years and constructing developmental trajectories in order to directly compare the children with autism with a typically developing group on these specific perceptual developments. Finally, we examined whether motion sensitivity on any of the tasks correlated with severity of symptoms in autism.

In the first experiment, children saw brief displays of either biological motion or scrambled motion, using a procedure similar to Blake *et al.* (2003). We found that the ability to distinguish biological motion from scrambled motion increased linearly relative to increasing CA, verbal and non-verbal mental age in the TD children, over this age range. This finding is consistent with data reported by Friere *et al.* (2006), which also demonstrated that sensitivity to biological motion continues to develop into middle childhood in the normal case. It also suggests that the task we used is sensitive to developmental change in this chronological age range.

In comparison, sensitivity to biological motion remained constant relative to CA, verbal and non-verbal mental age in the children with autism. There was little variation in scores for the autism group with d' values being tightly clustered around the mean value. This does not represent floor performance as d' values were above 0.05, and with a mean = 1.0 for the autism group and a mean = 2.3 for the TD group, thus comparable to those found in Blake *et al.*'s (2003) study (Figure 3, p. 155, shows a d' of approximately 1.2 in the autism group and 2.5 in controls). In contrast to Blake *et al.* (2003), we did not find that mental age was related to performance on

the biological motion task. It is therefore unlikely that children with autism were simply misunderstanding the instructions or that more general spatial skills account for their performance. Finally, since there was so little variability in thresholds across the autism group, it was not surprising that we found no correlation between performance and symptom severity as measured by CARS. This result contrasts with Blake *et al*. (2003) where symptom severity was related to sensitivity to biological motion.

In the second experiment psychophysical thresholds for motion and form tasks were established for each child and this enabled a comparison of performance on different motion tasks. Analysis of the typically developing children's data showed that sensitivity reliably improved with age on the biological motion, motion coherence and form-from-motion tasks. This is consistent with previous data suggesting that perceptual sensitivity on these motion tasks improves into middle childhood (Friere *et al*., 2006). In the autism group by contrast, thresholds for the detection of biological motion remained constant with increasing chronological age and increasing mental age, mirroring the findings from Experiment 1. Again, the fact that children with autism were scoring above floor level implies that their flat trajectory may reflect a functional rather than a measurement limitation. The autism group also showed no reliable relationship between motion coherence threshold and chronological age or mental age.

It is worth noting that our qualitative observation (Table 2) was in line with Milne and colleagues' study (2002), showing that a number of children with autism had thresholds within the normal range performance. However, this descriptive report requires to be validated with large populations in order to discuss the findings in terms of subgroups of autism disorders. In contrast to the other motion tasks, mental age did reliably predict performance on the form-from-motion task. When we compared the trajectories, we found that the *rate* of development relative to mental age (VMA and NVMA) in the autism group was similar to that of the typically developing children. We also found that the threshold at onset (the level of performance at the youngest age we tested, CA or MA) was higher in the autism group compared to typically developing children, suggesting that the children with autism are *delayed* rather than atypical relative to their mental age on the development of their ability to perceive form-from-motion.

When we examined the relative levels of performance across the three tasks we found that performance on the biological motion task differed most from the TD trajectory, significantly more than the motion coherence and form-from-motion task. There was also a significant correlation between performance on motion coherence and form-from-motion tasks, even when age and verbal mental age was taken into account; although this finding was non-significant when non-verbal mental age was partialled out. Importantly, performance on the biological motion task was unrelated to the other two tasks. Individual data showing those children with autism with thresholds within the 95% confidence interval of the TD developmental trajectory for each of the three tasks shows how performance varied considerably on the motion coherence and form-from-motion task, but not on the biological motion task.

The pattern we have observed suggests that the perception of biological motion may be specifically affected in autism, developing atypically regardless of perceptual abilities on other motion tasks. Could the pattern of atypical development and low sensitivity to biological motion found in almost all the children with autism be due to some general task constraint, for example sustained attention or maintaining task objective? This seems unlikely since the task demands of all three motion tasks in Experiment 2 were designed to be as similar as possible. Cross-task comparisons revealed a significant disparity between the biological motion task and the motion coherence or form-from-motion tasks. Furthermore, performance on the contour integration task was normal in the autism group, despite this task also involving the identification of a target embedded in noise.

In the third experiment there was a reliable relationship between age and performance on the contour integration task for both the typically developing children and the children with autism. The ability to perceive contours from Gabor patches was developing typically in the children with autism, with a similar rate of development and developmental onset to typically developing children. Previous findings using a traditional cross-sectional matching design have also yielded no differences in performance between children with autism and matched controls on contour integration tasks (Del Viva, Igliozzi, Tancredi & Brizzolara, 2006; Kemner *et al*., 2007).

How consistent are our data with the current theoretical accounts of motion perception impairments in autism? According to Bertone *et al*.'s (2003) complexity hypothesis, a general abnormality in neurointegrative mechanisms in autism results in an impairment in feature integration of complex stimuli (i.e. stimuli where integration involves feedback mechanisms beyond the level of V1) which should include all our motion tasks. Although not all children with autism have thresholds above what would be expected for their chronological or mental age on the motion tasks, the overall results are generally consistent with Bertone *et al*.'s complexity-specific hypothesis as the thresholds for biological motion tasks – at least at older ages – and both the motion coherence and form-from-motion conditions – across ages – were higher in the autism group. Bertone *et al*. (2003, 2005a, 2005b) also predict that perception of simple (first order) stimuli (where feature integration can be achieved at the level of V1) should be unimpaired in autism, and we indeed find support for this. The stimuli used in our third experiment could be described as simple

(first order) stimuli as integration of Gabor elements to identify a contour can be achieved using lateral connections in V1 (Kovacs *et al*., 2000), and our findings demonstrate that the ability to perceive contours using these stimuli is developing typically in autism.

Recently, Neri (2009) has suggested a two-stage processing model of biological motion perception where the local signals are first integrated into features (individual limbs) and then combined into whole PLD (Neri, 2009). Use of two different types of biological motion tasks demonstrated that even this initial integration in features is unlikely in autism. If featural processing could be used in recognition of biological motion, then this would give an advantage to the autism group in Experiment 1 but not Experiment 2, whereas we demonstrated poor performance on both these tasks. It is also worth noting that in the tasks used in the current study, children were explicitly directed to attend to biological motion stimuli. Differences between performance on explicit tasks versus spontaneous behaviour are common in autism, and it is possible that a task requiring spontaneous attention to biological motion could reveal an even greater deficit in the autism group.

Finally, Reiss *et al*. (2005) and Jordan *et al*. (2002) have shown typical development of biological motion perception alongside other motion perception impairments in Williams Syndrome and argued that this could be explained by the tendency of these individuals to be highly interested in social stimuli. The argument here would be that looking more at social stimuli may stimulate the development of brain networks responsible for perception of biological motion. In autism, by contrast, there is now a large body of evidence showing that children with autism look less at people in early development and it has been argued that a tendency to orient less to social stimuli lies at the heart of the disorder (Annaz, Milne, Campbell, Coleman & Swettenham, submitted; Dawson, Munson, Estes, Osterling, McPartland, Toth, Carver & Abbot, 2002; Klin,Jones, Schultz, Volkmar & Cohen, 2002; Swettenham, Baron-Cohen, Charman, Cox, Baird & Rees, 1998). What our data reveal for the first time is that perception of biological motion does not develop further between 5 and 12 years of age in autism, so that even during a period of development when one would normally expect an increase in the behavioural experience of looking at people, the ability to recognize or detect biological motion does not appear to be improve in almost all the participants with autism. Although the data do suggest atypical processing of biological motion with respect to age, verbal, and non-verbal function, until longitudinal data are available it is not possible to know whether the actual process of development in these children is atypical.

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