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Young Children with Autism Spectrum Disorder Do Not Preferentially Attend to Biological Motion

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Abstract Preferential attention to biological motion can be seen in typically developing infants in the first few days of life and is thought to be an important precursor in the development of social communication. We examined whether children with autism spectrum disorder (ASD) aged 3–7 years preferentially attend to point-light displays depicting biological motion. We found that children with ASD did not preferentially attend to biological motion over phase-scrambled motion, but did preferentially attend to a point-light display of a spinning top rather than a human walker. In contrast a neurotypical matched control group preferentially attended to the human, biological motion in both conditions. The results suggest a core deficit in attending to biological motion in ASD.

Keywords Autism spectrum disorder · Social stimuli · Attention · Biological motion

Preferential attention to social stimuli in humans can be observed early in development. In the first few days of life infants will orient towards social stimuli such as faces, the sound of language and human biological motion (Cassia 2004; Farroni et al. 2002; Fox and McDaniel 1982; Johnson et al. 1991). This attentional bias may be underpinned by a primitive neural pathway which ensures preferential processing of information relating to others of the same species. It has been shown not only in humans, but also in other vertebrate species (Johnson 2005) and there is strong evidence that the bias is innate; for example, newborn chicks raised in darkness, and therefore deprived of previous visual experience, will preferentially orient to images of heads and necks of hens (Johnson and Horn 1988) and to point-light displays depicting the biological motion of a hen (Vallortigara and Regolin 2006). The adaptive significance of such a bias in humans could be in identifying a predator or a potential mate, or even, given that humans are so social, in facilitating social engagement with others.

A good example of the type of information humans may prioritise is biological motion. Humans are typically highly sensitive to the movements of others: even relatively impoverished human point-light displays (point-lights moving on a screen as if attached to the joints of a moving person) can carry enough information for observers to identify an agent's action (Johansson 1973), emotional state (Atkinson et al. 2004), gender (Pollick et al. 2005) and identity (Loula et al. 2005). Visual sensitivity to biological motion emerges early in human development, in infants as young as two days old (Simion et al. 2008); recognition continues even when stimulus information is severely reduced (Neri et al. 1998), and it can be preserved in human observers even when other forms of motion perception are impaired (Jordan et al. 2002); all of which suggests a dedicated, early occurring mechanism for attention to and perception of biological motion. Such a mechanism could be important in supporting and developing social interaction

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with others, (e.g. through attention to others' movements in cues such as gaze direction or facial expression) and may be a potential precursor for subsequent social development (Klin et al. 2009), including the ability to attribute intentions to others (Frith and Frith 1999).

In this study we examine preferential attention for biological motion in children with autism spectrum disorder (ASD), a condition in which social impairments are widely thought to be fundamental (American Psychiatric Association 2006). Children with ASD show a number of atypical behaviours early in life including a lack of pretend play, impairments in imitation and joint attention, and a delay in language development (Chawarska et al. 2008). Perhaps one of the most striking features, though, is that toddlers and young children with ASD tend not to look towards other people as much as typically developing children do. Swettenham et al. (1998) found that during free play, 18–20 month old toddlers, later diagnosed with ASD, spent less time looking at people and displayed fewer gaze shifts between objects and people than typically developing children and children with developmental delay. In retrospective studies of home video-tapes of first birthday parties, it was found that children later diagnosed with ASD looked less at other people than typically developing children (Osterling and Dawson 1994). Dawson and colleagues also found evidence of an impairment in orienting to social stimuli (head turns towards clapping hands or the child's name being called) when compared to children with Down Syndrome and typically developing children (Dawson et al. 1998; Dawson, et al. 2004). One possibility is that the lack of attention to others may have its origin, at least in part, in a lack of preferential attention to biological motion early in development.

In typical individuals, visual experience attending to others influences sensitivity to human biological motion (Jacobs et al. 2004) with more experience leading to enhanced perceptual sensitivity. It is interesting then, that a number of studies now demonstrate a disruption in the perception of point-light displays of biological motion in children with ASD, either in the context of discrimination of biological motion from scrambled motion (Blake et al. 2003), perception of emotion from point-light displays (Moore et al. 1997), a lack of the usual perceptual advantage for point-light displays of biological motion over object motion (Kaiser et al. 2010a), impaired perception of what constitutes biological motion versus mechanical motion (Cook et al. 2009) or an abnormally flat developmental trajectory from 5 to 12 years in perceiving point-light biological motion embedded in noise (Annaz et al. 2010). Studies measuring neural activity when viewers with ASD observe biological motion point-light displays have shown a reduction in activity in the superior temporal sulcus (STSp) (Herrington et al. 2007; Kaiser et al. 2010b) the area usually associated with increased activity during perception of biological motion (Lichtensteiger et al. 2008; Pyles et al. 2007), and an area which becomes increasingly tuned to the perception of human movement in typically developing children, but not children with ASD (Pelphrey and Carter 2008).

Our hypothesis then is that young children with ASD may not preferentially attend to biological motion as do typically developing children. One consequence of this could be a reduced input of information on others' movements, which may impact on the development of perceptual sensitivity for biological motion and the later development of a range of social cognitive abilities.

One way to examine preferential attention for biological motion is by monitoring eye gaze in response to point-light displays. The advantage of using point-light biological motion stimuli experimentally is that they contain no other cues from the body (Johansson 1973). This means that in a preferential looking paradigm, for example, a bias toward biological motion versus scrambled motion cannot easily be accounted for by anything other than a specific preference for biological motion.

In a recent single case study, Klin and Jones (2008) examined preferential looking using point-light displays depicting biological motion and the same displays inverted and played backwards (non-biological motion). The stimuli were presented side by side and accompanied by audio files (e.g. peek-a-boo actions accompanied by speech sounds). In contrast to the control children (matched on verbal and non-verbal mental age), the child with autism did not preferentially look toward the biological motion display, whereas the typically developing children did. A follow up study examining preferential looking in a larger group of two year old children with ASD, and a control group matched on mental and chronological age (Klin et al. 2009) found that toddlers with ASD did not preferentially look toward point-light biological motion versus inverted point-light displays, whereas controls did.

At first glance these results appear to provide evidence for a lack of preferential orienting to biological motion in ASD; however, Klin et al's (2009) biological motion stimuli were novel in that they combined biological motion stimuli with sound. What the researchers noticed was that rather than reflecting a lack of preference for biological motion, the results for the ASD group reflected a positive preference for moments in the display when sound and movement were contingent (for example the movement of two point-lights coming together accompanied by a clapping sound). Since these contingencies were equally present in both biological motion and the inverted motion displays, children with ASD looked equally at the two displays. While this is an interesting finding, it does not tell us whether or not children with ASD preferentially orient to biological motion; only that the audio-visual contingencies override the biological motion as an orienting cue. In order to examine preferential attention to biological motion, point-light displays would have to be shown without an accompanying sound. Secondly, a feature of Klin et al's (2009) stimuli was that the biological motion depicted by the point-light displays involved specific actions designed to get the child's attention (what they describe as 'social approaches,' (Klin et al. 2009, p. 262). It is possible that the content of the biological motion (i.e. social gestures) was a confounding factor and that children with ASD specifically chose to ignore such stimuli because they involve social gestures—paying attention instead to other aspects of the stimuli. Thirdly, the control stimuli used were inverted biological motion stimuli played backwards. Although these stimuli look less like biological motion than upright stimuli, they still retain cues to biological motion in the temporal relationship between dot movements, groups of dots moving in relation to each other in the same way as they do during biological motion. This means that one would have to be cautious about how to interpret any lack of preference between stimuli. A more effective method of scrambling the biological motion stimulus is to play each individual dot temporally out of phase with the other dots in the stimulus. In these phase-scrambled stimuli the relationship between the dots is abolished whilst the density and individual dot movement is retained.

The experiment reported here differs from Klin et al. (2009) in a number of important ways. First we presented only visual point-light displays with no sound; second we presented biological motion stimuli depicting a person walking (i.e. not a social gesture) and third we used phase-scrambled point-light displays. We also conducted a second experiment comparing gaze fixation time to point-light biological motion displays shown alongside point-light displays depicting a spinning top. We predicted that on this second task we would find evidence of preferential looking in ASD and this would be important to counter the possibility that a lack of preference in our first experiment could be explained by a general tendency to attend equally to any adjacent point-light displays.

Method

Participants

Seventeen children with autism and 17 typically developing children participated in the current study (see Table 1 for details). All of the children in the group with ASD met established criteria for ASD as specified in DSM-IV (American Psychiatric Association 2006) and diagnosis was confirmed independently by a Clinical Professional using the Autism Diagnostic Observation Schedule (Lord et al. 2000). 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. There was no significant difference between the groups in chronological age or performance on the non-verbal Pattern Construction subtest from the British Ability Scale II (Elliot et al. 1997) however, children in the ASD group had significantly lower receptive language scores as assessed by the British Picture Vocabulary Scale II (BPVS) (Dunn et al. 1997)

Apparatus

The study was conducted using stimuli presented on a HP laptop running custom software written with Microsoft Visual Basic and presented on a 15-inch flat-panel LCD screen (1,024 × 768 pixel resolution; 60 Hz frame rate). Viewing distance was 40 cm. Eye movements were recorded by the means of a small camera mounted centrally above the laptop screen, and recordings were synchronised with display onsets.

Stimuli

Figure 1 shows images of the three types of point-light displays used. Point-light displays (Johansson 1973) were created using a markerless motion-capture method. The point-light walker (biological motion) stimulus was 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 presented from a side-view (approximately 7.8° visual angle in height) and remained in the centre of the panel as if walking on the spot. The phase-scrambled stimulus was created by taking the motion trajectories of each dot and playing them temporally out of phase with each other (hence controlling for display density and overall movement). Point-light walker and phase-scrambled walker were presented side by side as white dots on a black panel (17.1° × 17.1° visual angle). A non-biological motion object stimulus was created using the same technique as for the biological motion point-light walker. A video was used of a spinning top turning clockwise and leaning so that part of its circular form always touched a horizontal surface along with the lower point of its vertical axis. The video image was converted into a point-light display measuring 5° visual angle in height (13 dots: 11 dots creating the central rotating ring and one dot at each end of the axis). Point-light human (biological motion) and spinning top

Table 1 Mean chronological age, verbal mental age and non-verbal mental age for the children with ASD and TD children

Group (sample size)	Statistic	CA (in months)	BPVS-VMA (age equivalent in months)	PC—NVMA (age equivalent in months)
TD ($n = 17$)	Mean	67	79	77
	SD	13	14	13
	Range	44–89	52–99	50–99
ASD ($n = 17$)	Mean	66	62	76
	SD	13	13	15
	Range	47–88	44–82	54–93

TD Typically developing, *ASD* Autism group, *CA* Chronological age, *BPVS* British picture vocabulary scale (Dunn et al. 1997), *PC* Pattern construction subtest of the British abilities scale II (Elliot et al. 1997)

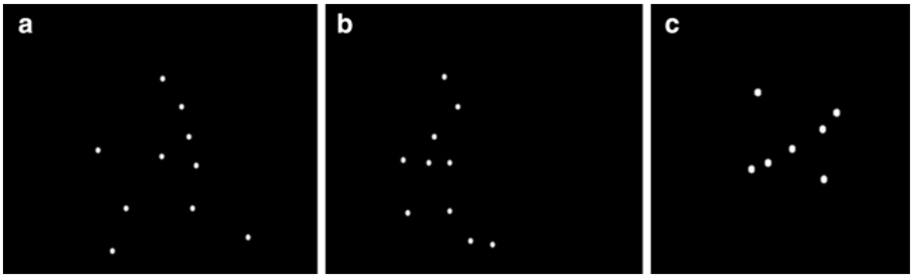

Fig. 1 Examples of (**a**) biological motion walker, (**b**) scrambled (**c**) spinning top. All elements appeared *white* signals on a *black* background

(non-biological motion) animations were presented side by side on black panels (17.1° × 17.1° visual angle)

Procedure

Each child viewed the stimuli on a laptop screen which showed two point-light displays side by side on each trial. In experiment one a point-light walker was shown alongside a scrambled point-light walker. In experiment two a point-light walker was shown alongside a point-light spinning top. Each experiment consisted of eight trials. The location of the biological versus the non-biological motion stimulus on each trial was randomized and counterbalanced so that each appeared on the left side of the screen as often as on the right. On each trial a fixation cross appeared at the centre of the screen for 2 s. After the fixation cross disappeared, a pair of stimuli were displayed side by side for 6 s.

Results

Coding Procedure

Video files of each child's gaze behaviour were analyzed off-line by two coders who were unaware of the location of the biological motion stimuli. For each trial the coder recorded the duration of time on that trial looking at either the left panel or the right panel. From this we calculated the percentage looking time at biological motion versus non-biological motion across the eight trials of each experiment. The second rater was blind to the diagnosis and identity of participants and coded 40% of the video recordings. Inter-rater reliability was high (Cohen's kappa 0.85).

Non-fixation Data

Analysis of the non-fixation data (saccades + off-screen fixations) revealed no significant differences between the groups in time not fixating at either of the panels in either experiment one (ASD $M = 7.2\%$, $\mathrm{SD} = 5.7\%$; TD $M = 9.3\%$ $\mathrm{SD} = 9.1\%$; $t(32) = 0.83$, $p > 0.05$), or experiment two (ASD $M = 10.1\%$, $\mathrm{SD} = 11.1\%$, TD $M = 7.4\%$, $\mathrm{SD} = 7.9\%$; $t(32) = 0.84$, $p > 0.05$). There was no difference between the groups in the number of saccades made in experiment one (ASD $M = 21.2$, $\mathrm{SD} = 4.4$; TD $M = 20.2$, $\mathrm{SD} = 3.2$; $t(32) = 0.8$, $p > 0.05$). There was, however, a group difference in the number of saccades made in experiment 2 with the ASD group making fewer saccades ($M = 12.8$, $\mathrm{SD} = 2.8$) than the TD group ($M = 16.6$, $\mathrm{SD} = 3.7$), $t(32) = 3.4$, $p < 0.05$.

Fixation Data

Experiment One

Figure 2 shows the percentage fixation time on the biological motion and the scrambled motion stimuli. Children with ASD were random in their gaze patterns (47.2% on the biological motion and 52.8% on scrambled motion), whereas typically developing children (TD) demonstrated a significant preferential attention to biological motion

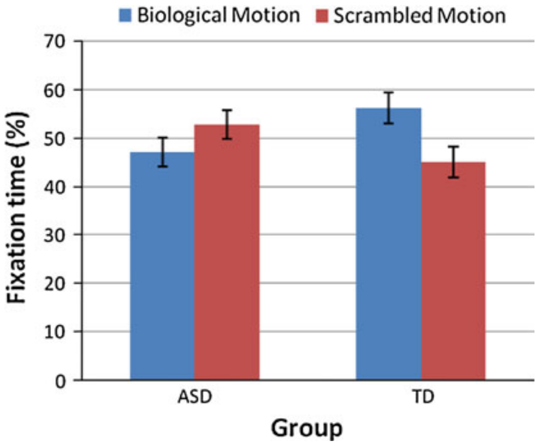

Fig. 2 Experiment 1—Mean fixation time on biological motion versus scrambled motion stimuli (*Error bars* show 95% confidence intervals indicating when performance differs from chance, i.e. when 50% performance is outside the *error bar* range)

(56.2% on biological motion and 43.8% on scrambled motion). We also carried out a mixed ANCOVA, covarying for verbal mental age, with group as the between subjects factor and display type as within subjects factor. Results revealed a significant interaction between group and display type $F(1,31) = 6.02$, $p < 0.05$ with the covariate of verbal mental age not significant ($p > 0.05$). Post hoc t tests revealed a significant difference between the groups in percentage fixation time on biological motion, $t(32) = 3.54$, $p < 0.01$, with TD fixating for longer than ASD. There was also a significant group difference in percentage fixation on scrambled motion, $t(32) = 3.54$, $p < 0.01$ with ASD fixating for longer than TD.

Experiment 2

Figure 3 shows the percentage fixation time on the biological motion and the scrambled motion stimuli. Children with ASD showed a significant preferential attention for point-light display of the spinning top (39.5% on the biological motion and 60.5% on object motion), whereas typically developing children demonstrated a significant preferential attention to biological motion (56.7% on biological motion and 43.3% on object motion). We also carried out a mixed ANCOVA, covarying for verbal mental age, with group as the between subjects factor and display type as within subjects factor. Results revealed a significant interaction between group and display type $F(1,31) = 32.1, p < 0.001$ with the covariate of verbal mental age not significant ($p > 0.05$). Post hoc analysis revealed a significant group difference with percentage fixation time on biological motion higher for TD compared to ASD, $t(32) = 5.22$, $p < 0.01$, and a group with percentage fixation time on object motion higher in ASD than TD $t(32) = 5.6, p < 0.01$.

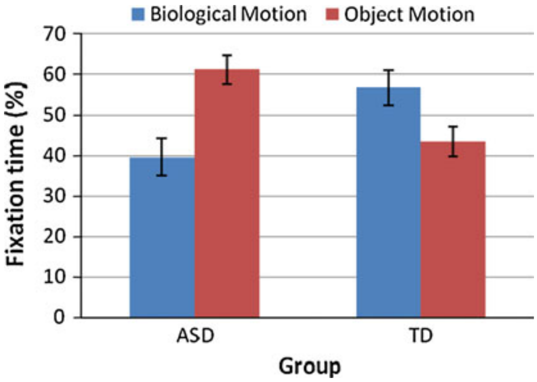

Fig. 3 Experiment 2—Mean fixation time on biological motion versus object motion stimuli (Error bars show 95% confidence intervals indicating when performance differs from chance, i.e. when 50% performance is outside the *error bar* range)

Discussion

This study provides evidence that young children with ASD do not preferentially attend to biological motion. When shown a series of point-light animations of biological motion alongside a phase-scrambled version of the same, children with ASD fixated for a similar amount of time on each type of stimulus. In contrast, typically developing children, aged 3–7 years and matched for age and non-verbal mental age, showed a significant preference for the biological motion stimuli. The lack of preferential attention for biological motion in the ASD group could not be explained by a general lack of attention overall to the two stimuli (the groups did not differ in time spent looking away from the point-light stimuli), or by an inability to shift attention between stimuli (both groups produced a similar number of saccades in experiment 1).

In a second experiment children were shown the same animation of biological motion alongside a point-light animation mimicking a spinning-top turning on its side on a flat surface. Children with ASD preferentially attended to the spinning top animation, while typically developing children preferentially attended to the biological motion. The finding is interesting since anecdotal reports often refer to young children with ASD having an unusual interest in objects with circular motion such as spinning wheels, and in one recent experimental study infants as young as 12 months of age who went on to receive a diagnosis of ASD displayed significantly more spinning and rotating of objects in their behaviour than did infants with no subsequent ASD diagnosis (Ozonoff et al. 2008). In our study, whether it is the repetitive motion, the circular motion, the recognisability of the point-light spinning top or some other factor which draws attention in ASD remains to be examined in further experiments. However, we note that in experiment 2 the spinning top appeared as a novel stimulus, whereas the same biological motion stimulus appeared in experiments 1 and 2. It is possible then that the children with ASD preferentially attended to the spinning top because of its novelty; in contrast such novelty would presumably be less important for the typically developing children when alongside a biological motion stimulus. We also found that children with ASD made fewer saccades in experiment 2 than did controls; it is unlikely that this can be explained by a general inability to shift attention in the ASD group as no differences in frequency of saccades were found in experiment 1, a more likely explanation is simply an increased interest in the spinning top in the ASD group. Finally, experiment 2 shows that the children with ASD were able to preferentially attend to one stimulus over another, reassuring us that the lack of preferential attention in ASD in experiment 1 could not be explained by a general tendency to always attend equally to two competing stimuli.

Our results are consistent with the fixation time data reported by Klin et al. (2009) despite some important differences between the studies. Our study used a phase-scrambled point-light display as the control stimulus, the motion of each individual dot being exactly the same as in the biological motion display but played temporally out of phase with each other. Our point-light biological motion animation simply depicted a person walking, whereas Klin et al's (2009) animations portrayed an adult "attempting to engage with a child" (e.g. playing peek-a-boo). The effect therefore doesn't seem to be specific to social gestures depicted in point-light displays. Our study displayed visual stimuli alone, meaning that a lack of preferential attention to biological motion could not be attributed to a preference for audio-visual congruency as reported by Klin et al. (2009). Although the preference for audio-visual contingencies in Klin et al's study is interesting, and relevant to orienting behaviour in the child's environment, our concern was only to identify whether the basic mechanism for preferentially attending to biological motion is impaired in ASD. We also studied children aged 3–7 years, whereas Klin et al. (2009) tested 2 year olds; our data therefore suggests that a lack of preferential attention for biological motion continues to be observed beyond the age of two. We view this developmental observation as being particularly important given that ASD is defined as a developmental disorder. There is no guarantee that an impairment observed early in childhood is necessarily obvious in later childhood or adulthood. For example, we have recently shown that there are no behavioural differences between a group of adolescents with ASD and typically developing controls on a test of biological motion perception, even though the same test revealed significant differences between younger ASD and typically developing controls (Annaz, et al. 2010; Jones, et al., Submitted). Further experiments will be needed to examine whether the lack of attentional bias for biological motion is found earlier in infancy in ASD.

There is now growing evidence that children with ASD are less sensitive in their perception of briefly presented and masked biological motion point-light displays (Annaz et al. 2010; Blake et al. 2003; Kaiser et al. 2010a, b) indexed by the increased signal to noise ratio needed for children with ASD to detect biological motion. Could a lack of preferential looking toward biological motion be the result of a less sensitive perception of the stimuli? We think that this would be unlikely because despite a reduced *sensitivity* in perception, a number of studies have shown that children with ASD can discriminate and even describe biological motion stimuli when they are played for long enough and unmasked (Annaz, et al. 2010; Hubert, et al. 2007; Moore et al. 1997; Parron, et al. 2008) as they are in the current preferential looking tasks. In our view it seems more likely that a lack of preferential attention for biological motion is a cause, rather than an effect, of reduced sensitivity in the perception of biological motion.

Why would evidence of an impairment in preferential attention to biological motion in ASD be so important? There is now increasing evidence that an attentional bias to information relating to other animals may be due to the existence of an innate neural pathway common to many species (Johnson 2005). This information not only involves faces and voices (or animal calls), but also the biological motion of a conspecific. Perhaps the most convincing data suggesting that the attentional bias for biological motion may be innate comes from a study by Vallortigara and Regolin (2006). They reported that newly hatched chicks, reared in darkness, show a preference for biological motion over scrambled motion even though these are the first stimuli the chicks have ever seen. Disruption to an innate predisposition to attend to biological motion and to other information relating to conspecifics could result in increasingly atypical experiences for infants and young children with ASD with cascading deleterious consequences for the downstream processing of social cues. This could occur directly via a disruption to the way in which information is processed or more indirectly by limiting the accumulation of socially relevant experience upon which social perceptual skills such as face processing and gaze processing are built (Dawson, et al. 2005; Grelotti et al. 2002). An early occurring impairment in preferential attention to biological motion in ASD may then be an important causal factor in later social processing impairments, and our data with 3–7 year olds as well as data from 2 year olds (Klin et al. 2009) at least hints at an origin in an earlier upstream impairment. However, we note that we do not yet have data from newborn infants with ASD and that there may be an alternative explanation for the lack of preferential attention to biological motion. For example a lack of attention to others might still be consistent with an account whereby the mechanism for attentional orienting to others is intact but is overridden by a top-down process such as an affective aversion to social information or a failure to find social information rewarding (New et al. 2010). Such an account would of course have to extend even to stimuli as impoverished as point-light displays of a person walking to be consistent with our data.

At the neural level the lack of input from social stimuli could result in a lack of specialisation in brain regions normally associated with social processing, and sometimes referred to as the social brain (Schultz 2005). One of the arguments regarding the social brain is that the visual system is tuned for the analysis of socially relevant input and that specific brain regions become increasingly specialised as a result of that input. There is now strong evidence that individuals with ASD show atypical neural processing in brain regions involved in the perception of basic social signals such as eye gaze and facial expression (Pelphrey and Carter 2008) and overlapping brain regions, such as the superior temporal sulcus (STSp), involved in the perception of biological motion (Saygin 2007) and thought to be critical for the perception of intentions from movement (Castelli et al. 2002). Studies of brain responses to biological motion, particularly in young children with ASD, might offer the possibility of identifying a neural marker for the condition. For example, a recent study measuring brain responses to biological motion, using fMRI, in a group of children with ASD (aged 4–17 years), unaffected siblings of children with ASD, and typically developing children, has shown that activity in STSp relates to severity of ASD (Kaiser et al. 2010a, b). Unaffected siblings also showed *distinct* brain responses to biological motion compared with typically developing children (despite a similar behavioural profile), suggesting a neural mechanism by which the unaffected siblings might compensate for their genetic risk for ASD; but they also showed *shared* brain responses with ASD children when viewing biological motion, suggesting a possible neuro-endophenotype (or ‘neural signature’) of ASD.

The current research in this area is clearly a long way short of proving evidence for a causal link between a lack of attentional bias for social stimuli such as biological motion and the impaired development of higher order cognitive abilities such as theory of mind in ASD. However, if we are searching for components of a ‘start-up kit’ for the development of higher order social cognitive skills as Frith, among others, has suggested (Frith 2001), then an impairment in this early occurring, basic mechanism for preferential attention to biological motion is a good contender.

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