Involuntary Interpretation of Social Cues is Compromised in Autism Spectrum Disorders

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A new social distance judgment task was used to measure quantitatively the extent to which social cues are immediately and involuntary interpreted by typically developing (TD) individuals and by individuals with autism spectrum disorders (ASD). The task thus tapped into the ability to involuntary ''pick up'' the meaning of social cues. The cues tested were social attention and implied biological motion. Task performance of the ASD and TD groups was similarly affected by a perceptual low-level illusion induced by physical characteristics of the stimuli. In contrast, a high-level illusion induced by the implications of the social cues affected only the TD individuals; the ASD individuals remained unaffected (causing them to perform superior to TD controls). The results indicate that despite intact perceptual processing, the immediate involuntary interpretation of social cues can be compromised. We propose that this type of social cue understanding is a distinct process that should be differentiated from reflective social cue understanding and is specifically compromised in ASD. We discuss evidence for an underpinning neural substrate.

Keywords: social cognition; visual illusion; involuntary processing; social attention; implied motion

Introduction

People typically interpret the abundance of social cues in a seemingly effortless manner. However, despite the apparent ease, the underlying processes are quite complex and only partly understood. Social cue interpretation is of vital importance as it allows us to make sense of the social world, i.e. it allows to instantly understand the intentions or feelings behind others' actions and to act appropriately. Understanding others' actions/minds is a key element of social cognition, defined as the capacity to perceive, interpret, and respond to social stimuli [Adolphs, 1999].

The idea that the processing of social stimuli is a distinct ability or skill, enabled by a dedicated neural substrate, has gained increasing support over the last decades and has led to the concept of a ''social brain'' [Brothers, 1990]. For example, studies in the monkey brain showed that cells in the superior temporal sulcus (STS) are specifically tuned toward biological stimuli—often in relation to environmental cues—suggesting a role for the STS in action perception/understanding [Jellema & Perrett, 2002, 2007; Perrett, 1999]. Imaging studies in humans corroborated this idea, and further highlighted the involvement of the amygdala, ventro-medial frontal, anterior cingulate and medial orbito-frontal cortex [e.g. Adolphs, 2003; Frith, 2001; Pelphrey, Morris, & McCarthy, 2004; Saxe, Xiao, Kovács, Perrett, & Kanwisher, 2004] and the mirror neuron system [Rizzolatti & Graighero, 2004] in processing social cues. Studies of developmental disorders have shown that social cognition can be selectively impaired, among many other spared cognitive abilities, as in people with autism spectrum disorders (ASD), or can be selectively spared (or even enhanced), among many impaired cognitive abilities, as in Williams syndrome [Frith, 2001]. Taken together, these findings support the notion that social stimuli form a distinct stimulus class, processed by a dedicated ''social brain'' [cf. Adolphs, 1999; Frith & Frith, 1999].

Actions and contextual cues are highly interwoven. An important category of contextual cues is provided by the actor herself; these are social cues such as gaze direction, orientation of the head, facial expression and implied biological motion [Jellema & Perrett, 2002, 2007]. Therefore, a mechanism mediating a successful understanding of a perceived action will have to incorporate the social cues that accompany the action. For example, the meaning of an agent reaching out her arm while her gaze is directed at

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Received December 12, 2008; revised June 6, 2009; accepted for publication June 16, 2009

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Grant sponsor: Helmholtz Research Institute.
Published online 29 July 2009 in Wiley InterScience (www. interscience.wiley.com)
DOI: 10.1002/aur.83

the site she reaches for is quite different from an identical reaching action but with her gaze directed elsewhere. In the former case we see the action as intentional, in the latter we may see it as accidental, but not as intentional [cf. Jellema, Baker, Wicker, & Perrett, 2000].

Humans typically interpret social cues in an automatic or involuntary manner without involvement of deliberate reasoning. The automaticity of this process prevents it from reaching awareness. Especially, bodily cues such as gaze direction, head orientation and body posture can provide a "window into the other's mind" [cf. Perrett, 1999]. The automation of the processing of these cues may have evolved under evolutionary pressures to facilitate the instantaneous understanding of others' intentions [cooperative or hostile; Dunbar & Shultz, 2007]. The unconscious inferences may considerably influence our conscious judgments of others [Bargh, 2006; Lieberman, Gaunt, Gilbert, & Trope, 2002; Satpute & Lieberman, 2006; see Bargh, 2007 for a review]. Failure of the automation of social cue processing surely compromises one's possibilities for successful social interactions. Such a failure has been proposed to be a crucial factor underlying the social deficiencies in ASD [cf. Frith & Frith, 1999].

ASD are characterized by impairments in social interaction, communication and imagination [American Psychiatric Association, 2000; DSM-IV-TR]. It has been argued that the social impairments reflect a difficulty (or inability) to understand minds, i.e. to read the behavior of others (and of oneself) in terms of mental states such as intentions, desires and beliefs [e.g. Baron-Cohen, 1995; Frith, Morton, & Leslie, 1991], and a failure to empathize [Baron-Cohen, 2005]. This is the Theory of Mind approach. Other approaches view social dysfunction as one of the manifestations of a more general underlying deficiency; e.g. as a deficiency in executive functioning [Russell, 1998], in a preference for local over global processing [Happé & Frith, 2006] especially following adolescence [Scherf, Luna, Kimchi, Minshew, & Behrmann, 2008], or in deficiencies in affective rather than cognitive domains [Hobson, 2002].

There are indications that social deficits seen in individuals with ASD are related to a failure in the automation of social cue processing rather than in the ability to understand intentions per se [Baron-Cohen, 1995]. Through explicit reasoning about others' intentions, individuals with ASD may compensate for an automation failure, but supposedly at the cost of falling behind in social interactions. In a similar vein, individuals with ASD typically have problems using the context to determine the pronunciation of homographs (words with one spelling but two meanings, each with its own pronunciation [Frith & Snowling, 1983]). However, when explicitly instructed to read for meaning, they performed as well as typically developing (TD) controls on this task [Happé, 1997].

The Social Distance Judgment (SDJ) Task

The current task was designed to tap into the ability to involuntarily "grasp" the meaning or implications of social cues that accompany actions, in individuals with and without ASD. The extent to which one possesses this ability is indicated by the extent to which one is biased by social cues when judging the distance between two animate objects. A response bias congruent with the meaning of the cues indicates accurate processing of social cue meaning.

The current task is fundamentally different from reflexive-orienting tasks using social cues. The latter investigate the ability to make a reflexive covert shift of spatial attention in response to e.g. head or gaze direction, which effect typically fades away after 500 msec following cue onset [Langton & Bruce, 1999]. In contrast, the SDJ task involves a deliberate decision about a geometrical distance, typically taking up to 2 sec to make, well beyond the time-window for reflexive orienting. Individuals with ASD tend to show intact reflexive orienting to perceived social attention conveyed by gaze cues [Kemner, Schuller, & van Engeland, 2006; Senju, Tojo, Dairoku, & Hasegawa, 2004; Swettenham, Condie, Campbell, Milne, & Coleman, 2003]. However, not much is known about the delayed effects of the involuntary processing of social cues.

The new task did not involve reaction times, spatial attention or language competency, and therefore any deficiencies in these domains could not disturb, or mask, the ability under investigation. Two social cues were tested, both conveyed via bodily postures/actions: (1) social attention and (2) implied biological motion. Visual cues to someone's social attention arise from their gaze direction, head or body orientation and gaze-target alignment. Visual cues to (implied) goal-directed actions arise mainly from leg and arm articulations, in relation to objects or environmental cues. Specifically, participants had to judge the geometric distance between two human cartoon figures, and compare this with the distance between two geometrical shapes, which were subsequently presented. We hypothesized that typical people would show a bias in their judgments congruent with the implications of the social cues conveyed by the cartoon figures. If so this would strongly suggest that they decoded or "picked-up" the social cues in an involuntary fashion, since the task did not require them to do so (the social cues were irrelevant to a correct task performance). In other words, stimulus processing at a literal/perceptual level (i.e. taking only the geometrical features of the objects into account) was sufficient to complete the task. We further hypothesized that individuals with ASD are compromised at the interpretation level, over and above intact processing at the perceptual level, and therefore would not show a response bias in their distance judgments.

Methods

Participants

Twenty-two participants, with a diagnosis of either Autistic Disorder (AD, $n = 10$) or Asperger Syndrome (AS, $n = 12$) based on DSM-IV criteria [American Psychiatric Association, 1994), were recruited from the Department of Child and Adolescent Psychiatry at Utrecht Academic Hospital. We recruited only high-functioning participants because of the task demands. The groups were pooled as we did not expect differences between them because the task did not depend on language abilities. The diagnostic evaluation was performed by a child psychiatrist and included interviews with parents, review of prior records and psychiatric observation. In addition, the parents/guardians of the participants completed the Autism Diagnostic Interview-Revised [ADI-R; Lord, Rutter, & Couteur, 1994]. All but two of the participants scored above cut-off on both the social and communication domains (these two were included in the analysis as further clinical diagnosis indicated ASD). Average values: social domain 18.3 (cut-off 10), communication domain 14.6 (cut-off 8), restricted and repetitive behaviors 4.8 (cut-off 3), age of onset 3.1 (cut-off 1). The age of the clinical group was 17.7 ± 4.9 (mean $\pm$ SD) years (range 12–26 years). Their mean total IQ score was 105.2 ± 12.4 (SD, range 75–120), with a mean total IQ score of 101.9 ± 15.0 for the AD group, and of 108.7 ± 5.9 for the AS group (WISC-III, WAIS-R and WAIS-III).

One TD control group was used ($n = 35$; 27 males, 8 females), matched with respect to IQ and sex. After applying selection criteria (see below) the mean age of the TD group was 20.0 ± 3.6 years (range 14–25), their mean IQ score was 107.7 ± 13.9. The TD group did not differ from the ASD group with respect to age ($P = 0.08$), IQ ($P = 0.51$) and sex ($P = 0.24$). In a separate experiment on 12 nonmatched TD controls (9 males, 3 females; age, 20.7 ± 3.6, mean $\pm$ SD) the effect of the shape of the geometrical objects on the illusion was tested.

The study was approved by the ethics committee of Utrecht University Medical Centre, and all procedures were in accordance with the Helsinki Declaration of 1975 (as revised in 1983). Written informed consent was obtained from the participants (or from parents/guardians) prior to the experiment.

Experimental Procedure

Participants were seated at a distance of 1 m in front of a 21 inch., PC monitor. Total duration of the experiment was 12 min. All instructions and visual stimuli were presented on the screen (E-prime, Psychology Software Tools Inc., Pittsburgh, PA, USA; 600 × 800 resolution). Six practise trials were given, after which the participant's understanding of the test instructions was verified.

A trial started with a 3 sec presentation of a single frame showing two cartoon figures at a distance of 2–6 cm from each other (Fig. 1). This frame was directly followed by the presentation of a mask (1 frame) for 1 sec, followed by a single frame showing two geometrical objects. The latter frame stayed on until a response was made. The participant had to compare the distance between the geometrical figures with the remembered distance between the cartoons, and select one of two responses: (1) "I think the two cartoons were closer together than the two geometrical objects," (2) "I think the two cartoons were farther away from each other than the two geometrical objects," by pressing one of two keys on the keyboard. For brevity we will refer to them as response "Cartoons closer" and response "Cartoons farther," respectively. Actually, the distance at which the geometrical objects were shown was always identical to the distance between the cartoon figures, except for the catch trials (see Exclusion of participants). The instructions explicitly stated that the distances between cartoons and blocks were never identical, but differed from just a few millimetres up to 2 cm (the catch trials). Absence of a response bias was taken to reflect ignorance on the part of the participant as to which of the two answers was

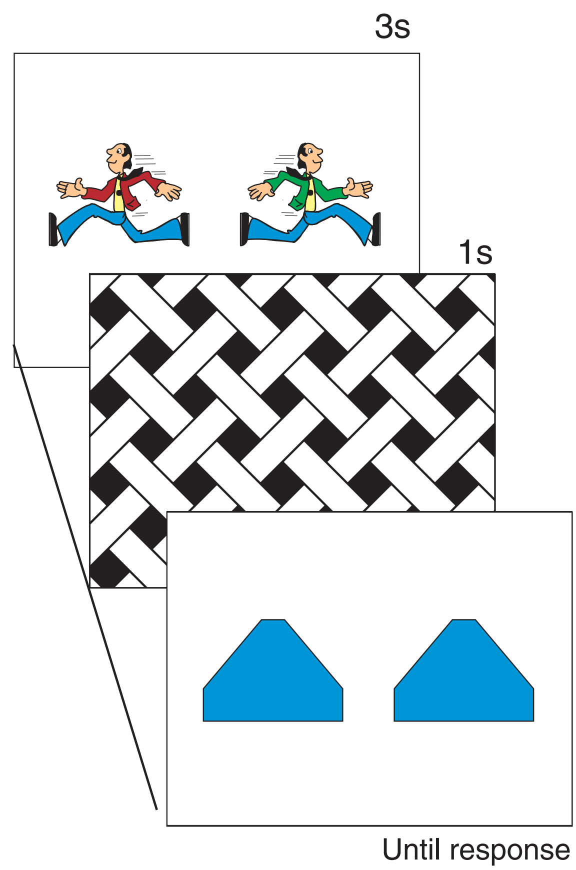

Figure 1. Example of the sequence of frame presentations in a single trial. Depicted is the congruent run-away condition. [Color figure can be viewed online at www.interscience.wiley.com]

correct. Participants were instructed to use the feet of the cartoon figures as reference point for judging the distance between the cartoons; for the geometrical objects the two vertical sides facing each other (indicated by arrows in Fig. 2a and b). The stimulus onset asynchrony (SOA) was 4 sec; participants were instructed that the speed of responding was irrelevant, provided it was made within 3 sec.

Stimuli

Stimuli were chosen from a cartoon library included in the CorelDRAW graphical package. One (male) cartoon identity was used, depicted in running and standing still position. The cartoon figures were always presented in pairs as each other's mirror-image (Fig. 2a and b). A different colour of the jacket indicated they were different individuals. Distances between the feet of the running cartoon figures were 2, 3 or 4 cm, and 4, 5 or 6 cm for static cartoon figures. The cartoons were considerably digitally adapted such that the mass distribution on either side of the vertical midline was identical, with the eye and head positioned exactly at the midline of the figure (Fig. 2c). In the running cartoons, the wind caused the jacket and tie to adopt a sideway position resulting in a

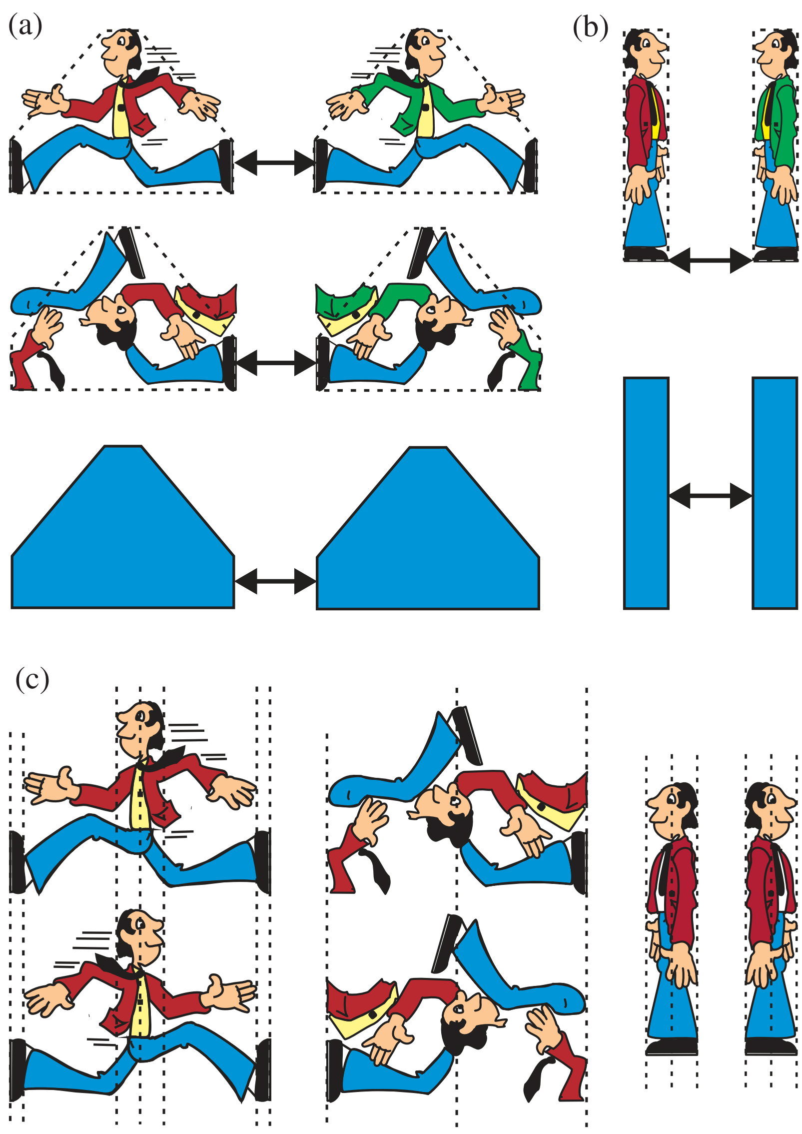

Figure 2. The stimuli (**a**, **b**). The outer dimensions of the cartoon figures matched the outer dimensions of the corresponding geometrical objects (dotted lines). The distances that had to be compared are indicated by arrows. (a) The congruent running figures (top), the Picasso figures (middle) and the geometrical objects (bottom). (b) The cartoons with unarticulated posture and the corresponding geometrical objects. (**c**) Symmetry in the cartoons. The figures were designed to have an equal mass distribution, and equal outer dimensions, on either side of the vertical midline. Conditions depicted are congruent running (left), Picasso (middle) and Static (right). [Color figure can be viewed online at www.interscience.wiley.com]

slight asymmetry in mass distribution. However, if anything, this would work against our hypotheses (see Discussion). All faces had the same (fairly neutral) expression. The maximal height and width of the geometrical objects matched those of the corresponding cartoon figures (Fig. 2a and b). The dimensions on the screen were 4.8 × 6.5 cm (height × width) for the running figures, and 6.4 × 1.3 cm for the static figures.

Conditions and Analysis

In the main condition the two figures were depicted in running postures (running condition), with the head and body of each figure pointing in the same direction (run congruent) or pointing in opposite directions (i.e. looking over the shoulder; run incongruent). In this way the two social cues, (1) the direction of social attention (either toward or away from each other), and (2) the direction of implied biological motion (either toward or away from each other), were manipulated. This resulted in four combinations of attention and motion: away/away, away/toward, toward/away and toward/toward (Fig. 3a), which were presented to all participants. We predicted overestimation of the distance in case the cartoons looked and ran away, and underestimation in case they looked and ran toward each other. The two incongruent conditions would help determine the relative contributions of the two cues.

To further disentangle the relative contributions of the two social cues, two additional conditions were used. (1) The major body parts of the running cartoon figure were repositioned, with the isolated head still positioned exactly at the midline of the figure, but pointing upward (Picasso condition, Fig. 2a and c). This meant that both the social attention and implied motion cues were absent. The Picasso condition was presented to all participants, except for 11 of the 28 matched TD controls. (2) The intact cartoon figure was in a static, standing still, posture (Fig. 2b and c). In this "static" condition, the social attention cue was still present (away/toward), but the implied motion cue was absent. The static condition was presented to all participants. Finally, in a separate experiment on 12 nonmatched TD controls, a condition was presented in which the shape of the geometrical objects was manipulated, in order to further test the idea that the low-level perceptual

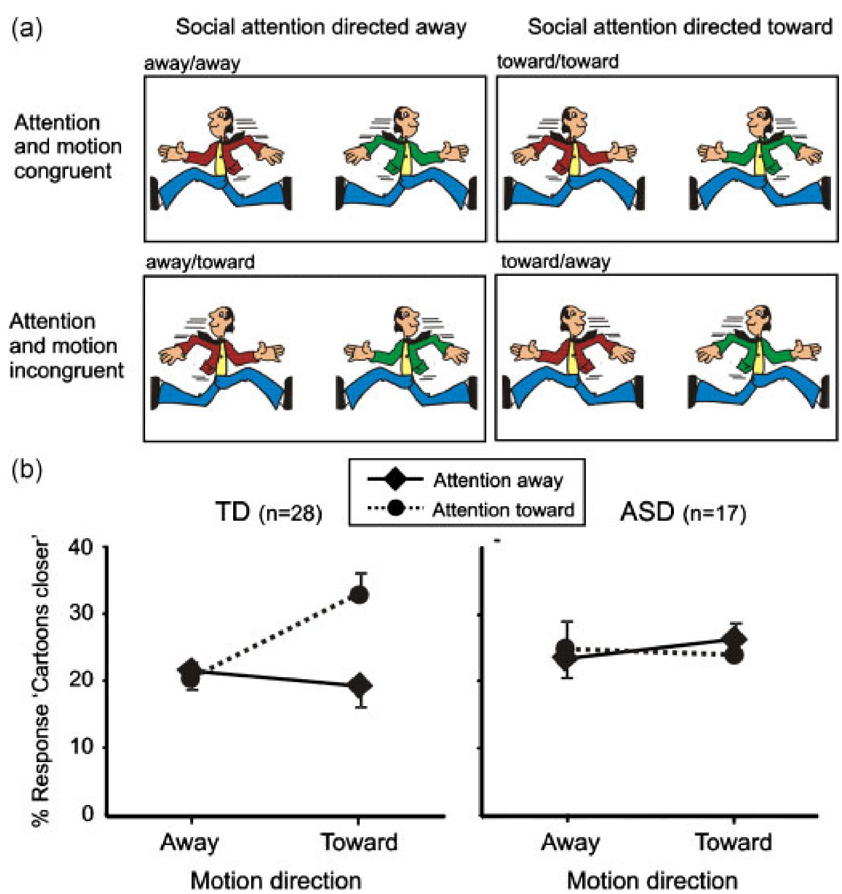

Figure 3. Response biases induced by the social cues. (**a**) Illustration of the stimuli in the running conditions. Head and body direction were either congruent (top panels) or incongruent (bottom panels). Social attention and motion were directed away from, or toward, each other, resulting in four conditions. (**b**) Mean scores (±SE) for the TD group (left-hand side) and ASD group (right-hand side). [Color figure can be viewed online at www.interscience.wiley.com]

illusion was related to the object's shape. All conditions (Running, Static and Picasso) were presented in random order with nine repetitions per condition. The manipulation of the geometrical objects was tested in a separate experiment (also with nine repetitions, but using TD participants only).

Repeated measures ANOVAs were used to test for response differences, where the dependent variable was the percentage of the response "Cartoons closer." Post hoc testing was done with *t* tests. Bonferroni corrections were applied where appropriate.

Exclusion of Participants

Nine catch trials were included, in which the distance between the geometrical objects was 2 cm larger or smaller than the distance between the cartoon figures, to identify participants not paying proper attention to the task. With proper attention paid, a 2 cm difference would easily be detected. Participants with more than one error on the nine catch trials were excluded. Using this rule, 14% (8/57) of the total number of participants was excluded: four participants in the clinical group (mean number of errors 3.5) and four in the TD group (mean number of errors 4). The mean numbers of errors for the accepted participants in these two groups were 0.6 and 0.2, respectively. Participants were further excluded if they gave the same answer on more than 95% of the trials (excluding the catch trials), which occurred in four participants (one with ASD and three TD controls). Of the five ASD participants that were excluded using these two criteria, three were diagnosed with AD and two with Asperger.

Results

The first thing to note about the scores of the TD controls ($n = 28$) is that in each of the four running conditions, the answer "Cartoons farther" was given much more often than the answer "Cartoons closer" (Fig. 3b, left-hand side). Across the four conditions, the answer "Cartoons closer" was given in 24% of trials, "Cartoons farther" in 76% of trials. This was most likely due to a low-level perceptual illusion (see below). On top of this general tendency to overestimate the distance between the cartoons, there were differences between conditions due to the social cues. These latter high-level effects, visible as a modulation of the low-level effect, form the main focus of this study. We will first examine the low-level effect.

Low-Level Effects Independent of the Social Cues

In the TD group, the ratio of about 1:4 for response "Cartoons closer" to response "Cartoons farther" in the "running" conditions contrasted sharply with the ratio of roughly 1:1 found in the additional "static" condition (just over 50% response "Cartoons closer," just under 50% response "Cartoons farther;" Fig. 4, left-hand side). The response "Cartoons closer" was given on average in 23.7% of the trials in the "running" conditions, and in 55.8% of trials in the "static" conditions. Since this distinct response pattern occurred irrespective of the manipulations of the social cues, the effect was deemed low-level, i.e. related to bottom-up perceptual processes. All 28 TD controls showed the low-level response bias. In the ASD group ($n = 17$) very similar ratios were found: in the running conditions the response "Cartoons closer" was given on average in 25.3% of trials (Fig. 3b, right-hand side) and in 53.9% of trials in the static condition (Fig. 4, right-hand side).

A direct comparison of the mean percentages of response "Cartoons closer" in the "running" and "static" conditions for both groups using a 2×2 ANOVA (with Motion type, running vs. static, as within-subjects variable, and participant Group, TD vs. ASD, as between-subjects variable) confirmed this. The analysis showed a main effect for motion type ($F(1,43) = 96$, $P < 0.001$, $\eta_p^2 = 0.70$), reflecting the large difference in low-level effect between running and static conditions. The main effect of Group was not significant

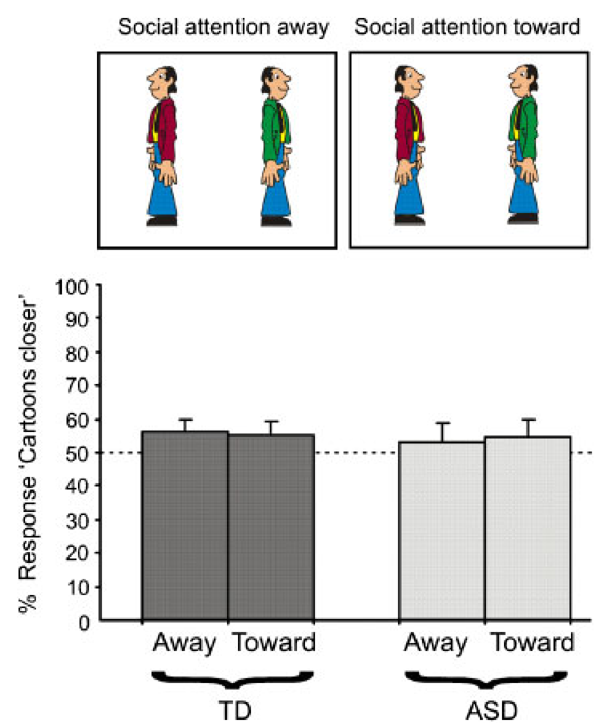

Figure 4. The static condition. The stimuli are shown at the top. In the absence of a motion cue, the social attention cue was no longer able to produce a response bias in the TD group (left-hand side). The response pattern of participants with ASD (right-hand side) was very similar to that of the TD controls. Dotted line indicates the 50% level. [Color figure can be viewed online at www.interscience.wiley.com]

($F(1,43) = 0.001$, $P = 0.98$, $\eta_p^2 = 0.000$) nor was the Motion type by Group interaction ($F(1,43) = 0.31$, $P = 0.81$, $\eta_p^2 = 0.005$), confirming that the TD and ASD groups were equally affected by the low-level effect. Of the 17 participants in the ASD group, 16 showed the low-level illusion, and 1 showed the reversed pattern.

We hypothesized that the low-level illusion was related to differences in the "massiveness" of the running and static cartoons as compared to their corresponding geometrical counterparts. The running cartoons had, due to their large indentations, a less massive appearance than the corresponding pyramidal-shaped geometrical objects. In contrast, the static cartoons did not have such large indentations; their "massiveness" better resembled that of the corresponding rectangle (see Fig. 2a and b). This might give rise to a perspective illusion, with the least massive objects being judged furthest away from the observer, and therefore inferred to be furthest away from each other (see Discussion for details).

We tested this idea in a separate experiment on 12 nonmatched TD controls, by introducing differently shaped geometrical objects. The contour lines of these objects contained indentations, which gave them a less massive appearance, with a surface area equal to that of the running cartoons (see shapes at the top of Fig. 5). The indented geometrical shapes indeed produced a significant increase in the occurrence of "Cartoons closer" responses, as compared to the solid geometrical objects in the same congruent running condition (Fig. 5; away/away condition, $t(31) = 2.6$, $P = 0.013$; toward/toward condition, $t(31) = 3.3$, $P = 0.002$). In the Static condition of this additional experiment (Fig. 5, left), the occurrence of response "Cartoons closer" was again around 50%.

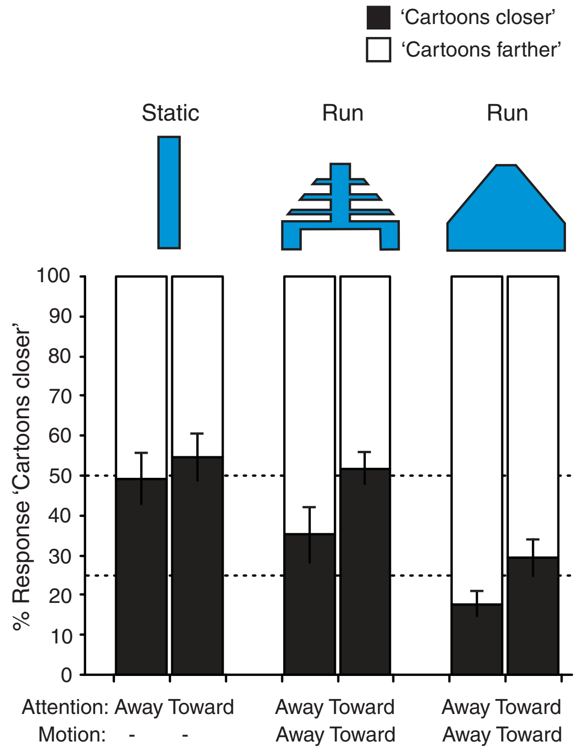

Figure 5. Manipulation of the shape of the geometrical object. When large indentations were introduced in the shape of the solid object (middle columns), a significant increase in response "Cartoons closer" was found in the congruent-running conditions, which effectively removed the low-level effect. Note that the high-level difference between the away/away and toward/toward conditions was unaffected by this manipulation. For comparison, the responses in the Static condition are shown (left), obtained from the same TD group. [Color figure can be viewed online at www.interscience.wiley.com]

High-Level Effects Induced by the Social Cues

Effects of the social cues, if any, would be visible as a modulation of the low-level tendency to overestimate the distances, and were deemed high-level effects (Fig. 3). The relative contributions of the two social cues were examined using a $2 \times 2 \times 2$ ANOVA with Attention direction (away vs. toward) and Body direction (away vs. toward) as within-subject variables, and Group (TD vs. ASD) as between-subjects variable. The only significant factors were the Social attention by Group interaction ($F(1,43) = 4.8$, $P = 0.034$, $\eta_p^2 = 0.10$) and the three-way Social attention by Body direction by Group interaction ($F(1,43) = 4.6$, $P = 0.037$, $\eta_p^2 = 0.10$). Because of the significant three-way interaction, results for the TD and ASD groups were analyzed separately in 2×2 ANOVAs (with a Bonferroni corrected critical α of 0.025). For the TD group, this analysis showed a significant effect for Attention direction ($F(1,27) = 15.9$, $P < 0.001$, $\eta_p^2 = 0.37$) and no significant main effect for Body direction ($F(1,27) = 15.9$, $P = 0.042$, $\eta_p^2 = 0.37$). Importantly, the Attention direction by Body direction interaction was significant ($F(1,27) = 15.9$, $P = 0.006$, $\eta_p^2 = 0.37$). T tests showed that the "look toward/run toward" condition evoked significantly more "Cartoon closer" responses than each of the other three conditions (vs. look away/run away: $t(27) = 4.2$, $P < 0.001$; vs. look away/run toward: $t(27) = 4.4$, $P < 0.001$; vs. look toward/run away: $t(27) = 3.8$, $P < 0.001$). TD participants thus believed the two agents to be closer together when they looked and ran toward each other as compared to when one, or both, of the cues was directed "away." None of the other contrasts was significant. For the ASD group, none of the factors reached significance.

Thus, neither attention direction nor motion direction influenced judgments of the ASD group, while for the TD group, attention direction and motion direction did influence the judgments, but only when they were both shown in "toward" direction. This combination produced a significant increase in the percentage of "Cartoon closer" responses.

To further examine the relative importance of both cues, and their interdependence, two more conditions were employed. In the Picasso condition, both cues were removed. If both cues were indeed necessary to bring out the response bias, then this condition should produce no high-level bias at all, but should leave the low-level bias intact. In the other condition (Static), the implied motion cue was taken out, rather than just changing its direction. The question here is can the social attention cue produce a bias in the absence of any motion cue?

Picasso Condition

In the Picasso condition, no coherent body form or implied motion was present (see Fig. 2a and c, and top panel of Fig. 6). This condition was assessed in 21 of the 28 TD controls. A one-way ANOVA for the TD group showed that the factor Condition (away/away vs. Picasso vs. toward/toward) significantly affected the scores ($F(2, 40) = 5.4$, $P = 0.008$, $\eta_p^2 = 0.21$; Fig. 6, left-hand side). Away/away differed significantly from toward/toward ($t(20) = 4.2$, $P < 0.001$), while neither of these conditions differed significantly from the Picasso condition after

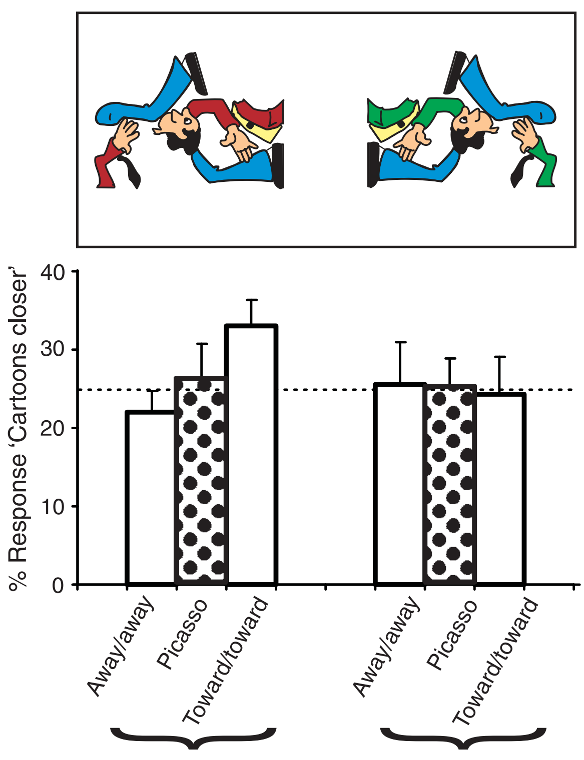

Figure 6. The Picasso condition. The stimuli are shown in the top panel. The TD group (left-hand side) responded with "Cartoons closer" in 25% of trials in the Picasso condition (dotted bars), midway between the percentages obtained in the away/away condition (18%) and toward/toward condition (29.5%). Participants with ASD (right-hand side) did not discriminate between the three conditions. The dotted line indicates the 25% level of response "Cartoons closer". [Color figure can be viewed online at www.interscience.wiley.com]

Bonferroni correction. In contrast, the ASD group showed no difference in responses between any of the three conditions ($F(2,32) = 0.05$, $P = 0.95$, $\eta_p^2 = 0.003$; Fig. 6, right-hand side). The percentage of the "Cartoons closer" score for the Picasso figures in both the TD and ASD group was close to 25%. These results suggested that the Picasso condition indeed represented a "neutral" stimulus, with responses merely determined by the low-level illusion. Thus, when both social cues were absent, the high-level response bias was effectively removed, and consequently, the two groups did not differ anymore in their distance judgments.

Static Condition

In the Static condition, the motion cue was removed by depicting the cartoon figure in standing upright posture (see top panels of Fig. 4), while the social attention cue remained intact. The static condition was assessed in all participants. The TD group did not discriminate anymore between the "look away" and "look toward" conditions ($t(27) = 0.31$, $P = 0.76$), nor did the ASD group ($t(16) = 0.23$, $P = 0.82$; Fig. 4). Thus, whereas in the TD group the social attention cue had an effect when presented as part of a running body posture (Fig. 3b), the same social attention cue had no effect when presented as part of a static standing body posture.

Variability in High-Level Response Bias

Given the relatively small number of nine repetitions per condition, a large variability at the individual level was expected. Indeed, even though the ASD group as a whole did not show a net high-level bias in any of the conditions, individual ASD participants did, but the directions and strengths of their biases showed a broad distribution resulting in the absence of a net effect. Of the 17 ASD participants, 5 showed a positive bias (3 AD and 2 AS), 7 a negative bias (3 AD and 4 AS) and 5 no bias (2 AD and 3 AS; Fig. 7a). The AS and AD groups did not differ from each other in response bias ($t(15) = 0.30$, $P = 0.76$). The response biases shown in Figure 7 were derived from the compatible running condition and were calculated as the percentage of response "Cartoons closer" in the toward/toward condition minus the percentage "Cartoons closer" in the away/away condition. A positive sign thus indicated that the direction of the bias was congruent with the social cues, a negative sign indicated a bias opposite to the directions of the social cues.

In contrast, the significant response bias at the population level in the matched TD group ($n = 28$) was supported by the vast majority: 17 TD controls showed a positive bias, 9 showed no bias and only 2 showed a negative bias in the congruent running condition (Fig. 7b).

Additional sources of response variation at the individual level might be formed by age and IQ. However, we found that both did not correlate significantly with test

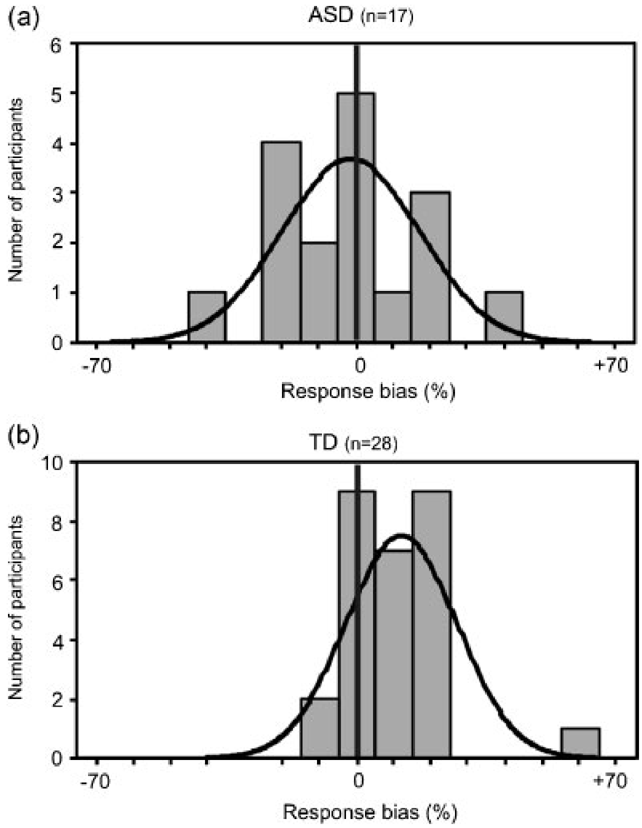

Figure 7. Distribution of the individual high-level response biases. (**a**, **b**) Individual response biases in the congruent running condition. (a) Individuals with ASD showed response biases that were widely distributed resulting in a net absence of bias. (b) The vast majority of the TD controls showed a response bias that was congruent with the social cues ("positive" sign), or no bias, while only two TD controls showed a small incongruent bias ("negative" sign).

scores (age: ASD group, $r = 0.40$, $P = 0.13$; TD group, $r = 0.032$, $P = 0.87$; IQ: ASD group, $r = 0.30$, $P = 0.29$; TD group, $r = -0.11$, $P = 0.58$; two-tailed Pearson correlation).

Discussion

This study used a new social distance judgement (SDJ) task to explore the extent to which social cues, i.e. the direction of someone's attention and implied biological motion (or goal-directed actions), are processed involuntary up to and including the interpretation level, by TD individuals and by individuals with ASD. The new task tapped into the ability to involuntary decode the meaning/implications of socially relevant stimuli. We hypothesized that this ability might be selectively compromised in autism. The results of the current experiments supported the hypothesis, in that the ASD group did not show a response bias congruent with social cues when making judgments about the physical distance between cartoon figures, while the TD group did show such a response bias. We labelled this response bias, or illusion, high-level, as it was induced by the meaning of the social cues. In addition, responses were influenced by a low-level or perceptual illusion, to which the TD and ASD groups were equally susceptible.

High-Level Illusion Induced by the Social Cues

The TD and ASD groups differed markedly with respect to the processing of the two social cues. The TD group showed significantly more underestimation of the distance in the "Attention toward/Motion toward" condition than in the other three conditions, while the ASD group did not discriminate between any of the conditions. The congruent response bias of the TD group indicated they involuntary processed the social cues, while the absence of such a bias in the ASD group suggested they did not.

TD and ASD participants did not differ from each other in the incongruent running conditions, in which one cue facilitated underestimation and the other overestimation. In principle, the cues might have interacted, as is shown in studies using reflexive-orienting to social cues in typical participants [e.g. Hietanen, 2002]. Such studies demonstrated a superiority of incongruent over congruent head and body cues. However, this is a reflexive response, which quickly fades away (within 500 msec) and therefore will not have played a role in the current paradigm in which the SOA is relatively long SOA (4 sec).

Specific Contributions of the Two Social Cues

The social cues contributed to the response bias in the TD controls in an interdependent way. Taking out both cues, as realized in the Picasso condition, resulted in the absence of the high-level bias, suggesting that there were no other unknown factors involved in bringing about the high-level illusion.

The social attention cue. Since taking out the motion cue (Static condition) completely removed the bias, it follows that the social attention cue needed the running body posture to become effective. This was also found in the main experiment where the "look toward/run toward" condition produced an underestimation of the distance while the "look toward/run away" condition did not. The ASD group was not influenced by the attention cue. It should be noted that this finding is not incompatible with recent reports that individuals with ASD show reflexive orienting to gaze cues. Reflexive orienting to gaze cues does not imply that the meaning of the gaze cue is decoded, which however is required to produce a response bias in our task. Further, our paradigm differed fundamentally from the reflexive-orienting paradigms, in that the latter typically use SOAs of 300 msec (vs. 4 sec in our task), and use reaction times as dependent variable (vs. perceptual distance judgments in our task). This suggests that automaticity in ASD individuals is undisturbed as long as it does not involve decoding the meaning of the social cue (reflexive orienting), and gets disturbed when it does involve decoding meaning (the current task).

The motion cue. Taking out the attention cue (while leaving the implied motion cue intact) would have balanced the set of conditions. However, with the current stimuli this is hard to realize. Blackening or removal of the head of the cartoon figure would not entirely remove the attention cue, as body posture takes over as indicator of attention direction when gaze and head cues are not visible [Perrett, Hietanen, Oram, & Benson, 1992]. The lack of this condition is a limitation of this study, and should be addressed in subsequent studies. However, the finding that the ''look away/run toward'' condition did not work, while ''look toward/run toward'' did work, suggests that the motion cue on its own is not able to cause an effect. Further studies need to explore whether this difference might be related to different intentions conveyed by the congruent vs. incongruent condition. Incongruent body postures can be superior to congruent ones with regard to inducing reflexive orienting [cf. Hietanen, 2002]. However, as noted above, our SOA excluded the effects of reflexive orienting. Possibly, the relative increase in underestimation of the distance in the ''look toward/run toward'' condition as compared to the ''look away/run away'' condition was due to the additive effect of the directions of the social cues, while in the incongruent conditions the directional effects cancelled each other. Such a process would be consistent with the shared underlying approach-avoidance signal value of the cues [Adams & Kleck, 2005].

The effect of the implied biological motion cue may have been related to the social implication of running toward—or away from—someone, to its representational momentum (RM), or to both. RM is the phenomenon that the motion implied in a still picture of an object may give rise to a distortion of the remembered position of the object [Freyd, 1983], and is sensitive to knowledge, beliefs and expectations [Reed & Vinson, 1996]. A single still image of an object in motion can be enough to produce RM effects [Kourtzi & Kanwisher, 2000; Lorteije et al., 2006], so its contribution in the current task cannot be ruled out. The question of whether individuals with ASD have specific deficits in the processing of (biological) motion, whether real or implied motion, is still largely unexplored. Individuals with ASD have been shown to be less sensitive to second-order texture-defined motion stimuli [Bertone, Motron, Jelenic, & Faubert, 2003], and may be specifically impaired in identifying biological motion [Blake, Turner, Smoski, Pozdol, & Stone, 2003], but a possible impairment for implied motion has not been investigated.

It should be noted that this study used cartoon figures (as these allowed for extensive digital adaptation without looking ''strange,'' see Fig. 2c) rather than pictures of real bodies. It seems likely though that the social cue results can be extrapolated to real stimuli. Neural activation measures typically do not discriminate between real and schematic faces [e.g. Sagiv & Bentin, 2001], while behaviorally it has been shown that schematic faces can even enhance responses compared to real faces, as e.g. in reflexive gaze cueing studies [e.g. Hietanen & Leppanen, 2003].

The Low-Level Perceptual Illusion

A general tendency to overestimate the distance between the running cartoon figures, irrespective of their direction of running or looking, was consistently found in all participants in very similar proportions (roughly 25% response ''Cartoons closer,'' 75% ''Cartoons farther''). A number of findings suggested that this reflected a perceptual, low-level illusion, unrelated to the social cues. Removal of the social cues while keeping the surface area and outer dimensions the same (Picasso condition) did not affect the illusion, as again a 1:4 response ratio was obtained. The social cues thus did not contribute to it. The Static condition (cartoon figures in unarticulated upright posture) provided an important clue as to what might have caused the illusion. This condition produced roughly equal proportions of the two responses. After eliminating the social cues, the main difference that remained between the static and running condition was the difference in the appearance of the massiveness of the cartoon and of the corresponding geometrical shape. That is, the running cartoons, due to their indentations, looked smaller than their corresponding geometrical objects, while the static cartoons appeared to have the same size as their corresponding geometrical objects. The further away an object is from the observer, the smaller its retinal image. Therefore, the running cartoons gave the impression of being furthest away from the observer. Then, taking perspective convergence into account, the participant (unconsciously) inferred that the actual distance in a three-dimensional world between the running cartoons would have been bigger than that between the geometrical objects, and consequently indicated that (in the two-dimensional stimulus display) the cartoons were further away from each other than the corresponding geometrical objects. Thus, inferences that apply to a three-dimensional world seep through into the two-dimensional screen display.

The Müller–Lyer illusion seems to corroborate our interpretation. This illusion involves an apparent difference in the perceived length of a line or gap, when arrow heads, vs. arrow tails, are attached to its ends. An often cited explanation [Gregory, 1963] assumes that the line with arrow tails gives rise to two concave corners in the 3D world, the line with arrow heads to two convex corners. The idea is that the central line appears further away from the observer when it connects concave corners rather than convex corners. Therefore, the line with arrow tails appears longer as a compensation for being further away. We assume that a similar compensation occurred in our task. Support for this explanation was obtained by replacing the solid geometrical objects with indented objects, which yielded a "Cartoons closer:Cartoons farther" ratio of 45:55%, thus largely removing the low-level illusion.

The finding that the participants with ASD and the TD controls were equally susceptible to the low-level illusion is important because it indicates that basic perceptual processing of the stimuli was intact in the individuals with ASD, and that they did not gave their responses at random.

There is some controversy as to the extent to which visual illusions are resisted in autism. It has been suggested that in cases where central coherence (i.e. an inducing context) plays a role in producing the illusion in typical people, individuals with ASD are better able to resist it. However, equal susceptibility in individuals with ASD and TD controls to a variety of central coherence-based visual illusions has been reported, including the Müller–Lyer illusion [Mitchell & Ropar, 2004; Ropar & Mitchell, 1999].

Possible Confounding Variables

Attention paid to the task. We can exclude the possibility that individuals with ASD did not pay proper attention, or that they even responded at random, as those participants that made more than 1 error on the nine catch trials were excluded from the analysis. Using the above criterion, very similar percentages of the ASD and TD groups were excluded, indicating that the ASD group was not especially prone to paying poor attention. Moreover, the very similar responses in both groups to the low-level illusion also indicated that the ASD group paid proper attention (otherwise the illusion would not work).

Local vs. global processing. The extent to which, and the circumstances under which, individuals with ASD show a preference for processing local details over global structures is subject to debate [see Happé & Frith, 2006, for a review]. Recent studies have suggested that rather than being impaired in processing global form, individuals with ASD process global forms as TD individuals do, yet have a preference for local processing [e.g. Behrmann, Thomas, & Humphreys, 2006]. The current finding that 16 of the 17 individuals with ASD fell for the low-level illusion indicates that they did perceive the cartoons as a whole, as perceiving the entire contour of the stimuli (cartoons and geometrical blocks) is a prerequisite to experience this low-level illusion. A strategy of zooming-in onto details of the figure is unlikely to give rise to this illusion.

Visual working memory. Individuals with ASD may have an impaired visual working memory [Russell, 1998]. Could this have contributed to the results? The findings that the ASD and TD groups showed similar responses on the catch trials and a similar susceptibility to the low-level illusion suggests it did not. These findings imply that ASD participants were able to hold the image of the two cartoons in their visual working memory for at least 2 sec. Therefore, problems in visual working memory in the ASD group, if any, did not interfere with task performance.

Neural Substrate for Processing Social Cues

Over the last decades fundamental insights have been obtained regarding brain structures underpinning the capacity to decode (the meaning of) social cues, which involve the superior temporal sulcus (STS) [Allison, Puce, & McCarthy, 2000; Jellema & Perrett, 2002, 2007; Pelphrey et al., 2004; Saxe et al., 2004], the temporal pole, amygdala, ventro-medial frontal and medial orbito-frontal cortex and the anterior cingulate cortex [e.g. Adolphs, 2003; Frith, 2001; Haxby, Hoffman, & Gobbini, 2002]. In particular, the STS seems well equipped to represent both the perception and understanding of the two social cues used in this study. STS cell populations provide a visual description of others' faces, gaze direction, direction of attention, bodies and their actions [Perrett et al., 1992]. But even more relevant, many of these STS cells take the context or goal of the action into account [Perrett, 1999; see Jellema & Perrett, 2007, for an overview], allowing to predict subsequent actions and consequences, and to represent the implications of the social cues. Also relevant for this study is that the STS represents not only the actual motion but also the implied biological motion present in static articulated postures [Jellema & Perrett, 2003]. There has recently been support from imaging studies for the suggested role of the STS (especially in the right hemisphere) in representing the goal-directedness and volitional intentionality underlying biological actions [e.g. Castelli, Frith, Happé, & Frith, 2002; Pelphrey et al., 2004; Saxe et al., 2004]. The absence of automation of social cue processing in individuals with ASD, as suggested by this study, may well be related to neuronal abnormalities in the STS as reported in individuals with ASD [e.g. Zilbovicius et al., 2006].

In conclusion, the current results suggest that the involuntary processing of social cues may be a distinct process, which is compromised in ASD. This may in turn cause a cascade of social interactive problems. For individuals with ASD it may require effort and voluntary reasoning to decode social cues, whereas typical people just "see" the intention [cf. Klin, 2000]. In phenomenological terms one might say that for individuals with ASD the intention is not given *in* the action.

Acknowledgment

We thank David Perrett for helpful comments on the manuscript.

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