

Failure to read motor intentions from gaze in children with autism

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Abstract

A core feature of autism is the abnormal use of gaze to attribute mental states to others, and thus to predict others' behaviour. An untested idea is whether this dysfunction is confined to mental states having a propositional content, such as beliefs and desire or extends to motor intentional states which allow one to make inferences about the actions of others. This study used kinematics to examine the ability to use gaze to inform one about the motor states of another in normal and autistic children. In each trial two participants, a model and an observer, were seated facing each other at a table. In three experimental blocks the model was requested to grasp a stimulus, to gaze towards the same stimulus, and to gaze away from the stimulus without performing any action. The task for the observer was to grasp the stimulus after having watched the model perform her task. We observed that normal children showed facilitation effects in terms of movement speed following the observation of the model grasping or simply gazing at the object. In contrast, autistic children did not show any evidence of facilitation in these conditions. Neither normal nor autistic children showed evidence of facilitation when the model's gaze was not directed towards the stimulus. These findings demonstrate that, in contrast to normal children, children with autism fail to use information from the model's action or gaze to plan their subsequent action, and that in autism the inability to use of another person's gaze produces a lack of understanding of the motor intention of others.

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1. Introduction

Autism is a pervasive developmental disorder associated with a unique profile of aberrant social behaviour (Kanner, 1943). One of the components of the social communication deficits in autism is the abnormal encoding of gaze (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; Volkmar & Mayes, 1990; Senju, Tojo, Yaguchi, & Hasegawa, 2005). Consistent with this, Baron-Cohen et al. (1995) found that children with autistic features seem to be blind to the mental significance of another's gaze. Whereas normal children use eye-direction as a cue for reading mental states such as desire and goals, children with autism failed to use eye-direction to infer the mental states of others. In particular, children with autism failed to recognise that through gaze a model was trying to communicate her interest in something.

A clear case of the role of the eyes in communication arises when we try to get someone to do something by catching their eyes and directing their attention towards a salient object without moving either the head or hands, or producing any vocalization. In such cases, the observer treats the person's eye-direction as one way in which a person can point to, communicate what she wishes to do or request that something to be done with an object. In this respect, gaze direction can be interpreted as an ostensive act and thus the observer searches for plausible intentions behind the act. Gaze direction can also be a relevant cue for perceiving the 'motor' disposition and intentions of other individuals towards a specific object.

Along these lines, given the lack of comprehension of intentions and goals suffered by children with autism (Phillips, Baron-Cohen, & Rutter, 1992), it could be predicted that they would also have difficulty in understanding that the eyes communicate information about a person's motor intentions.

The goal of the present study was to determine whether children with autism have a disadvantage in the coding of gaze direction which prevents them from predicting the motor behaviour

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of others. Kinematic analysis allows one to examine the facilitation effects on action following the observation of a model performing an overt action towards an object or simply gazing towards the very same object (Castiello, 2003; Castiello, Lusher, Mari, Edwards, & Humphreys, 2002; Edwards, Humphreys, & Castiello, 2003). For instance, observing a model performing a reach-to-grasp movement facilitates the same action performed by an observer immediately after upon the same object. Importantly, similar facilitation effects are evident on the observer's kinematics following the observation of a model simply gazing towards the same object (Castiello, 2003; Edwards et al., 2003). Even more strikingly, if the observers are prevented from using information about the model's gaze, facilitation effects are not evident (Castiello, 2003). The interesting suggestion here is that the observer can infer from the model's gaze how the model would act upon that object. In turn this possible inference about the model's motor intentions would prime the observer's motor system producing facilitation effects in their own subsequent movement.

If this notion is correct, we might predict a direct link between the coding of gaze direction and automatic motor priming. This would provide a crucial test for the hypothesis that autistic children have difficulty in understanding that the eyes provide information about a person's motor intentions. If gaze coding is crucial to triggering facilitation effects primed by another person's action then children with autism should not show the kind of facilitation as those described above in healthy participants.

We designed a kinematic study in which the normal and autistic subjects observed a model either grasping or simply observing an object. Subsequently the subjects were requested to perform a grasping action towards the same object. These two conditions were compared to a control condition in which the model was standing behind the object performing neither a grasping nor a gazing action. Our core finding was that in contrast to normal children, children with autism did not show any type of motor facilitation following the observation of either a grasping or a gazing action towards an object.

2. Methods

2.1. Participants

Twelve high-functioning autistic children (six males and six females, 10–13 years old, mean 11.1 years; see Table 1 for details) and 24 controls (six males and six females, 10–13 years old, mean 11.9 years) with no reported neurological or academic problems participated in the study. All children were right-handed reported normal or corrected-to-normal vision, and were naive as to the purpose of the experiment. The groups were matched by age and sex. They attended one experimental session of ~1 h duration. The patients were diagnosed according to the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV) criteria for autism. IQ was measured with the Wechsler Intelligence Scale for Children (WISC-R). The score for all the autistic children was in the range of 90–109. The score for all the control children was in the range of 95–118. The Childhood Autism Rating Scale (Schopler, Reichler, & Roehen Renner, 1993) was administered at the ages of 4–8 years by an experienced clinical psychologist. At the time of the experiment all of the children with autism were attending special education classes for autism. None were on medication. The study was approved by the Royal Holloway, University of London Ethical Committee.

Table 1
Characteristics of children with autism

SS	Age	Sex	Hand	IQ score	CARS total score ^a
S1	10.2	F	RH	105	35
S2	10	F	RH	98	36
S3	13	M	RH	109	33
S4	10.5	M	RH	96	35
S5	10	M	RH	102	33.5
S6	13.1	F	RH	94	37
S7	11.2	M	RH	102	32.5
S8	10.6	M	RH	108	34
S9	11	F	RH	108	36
S10	13	F	RH	97	34
S11	10	F	RH	100	33
S12	11	M	RH	103	34.5

CARS, Childhood Autism Rating Scale.

^a Total score of 30–37 = mild autism.

2.2. Stimulus

The stimulus was a translucent plastic sphere (diameter: 5 cm) positioned at a distance of 30 cm from the hand starting position along the subjects' mid-sagittal plane (Fig. 1). Two LEDs were located inside the stimulus (Fig. 1). The LEDs were connected to two metallic contacts on the exterior of the spheres. These contacts met with three other metallic plates (one to the right, one in the center, one to the left) that were fixed to the table and connected to a PC.

2.3. Procedure

In each trial two participants, a model and an observer, were seated facing each other at a table (see Fig. 1). Twelve healthy control participants acted as models for both control and autistic participants. Twelve healthy participants and all of the autistic participants acted only as observers. Artificial lighting within the room allowed the model and the observer to see each other and the experimental set-up clearly. The black working surface measured 90 cm × 90 cm and was smooth and homogeneous. Prior to each trial both the model and the observer put their right hand on their respective starting positions (diameter: 5 cm) positioned 20 cm in front of their mid-line. Three conditions were used:

Action condition. In this condition the stimulus was illuminated, indicating to the model to reach towards and grasp the target. The stimulus remained

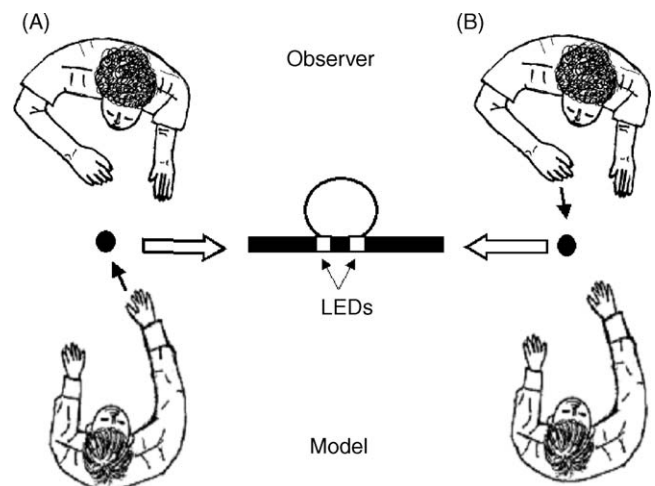


Fig. 1. Graphical representation of the experimental set-up. Panel 'A' shows the model reaching towards and grasping the object while being watched by the observer. Panel 'B' shows the observer performing the same reach-to-grasp movement after having observed the model acting upon the object. Filled arrows indicate the subject who is reaching towards the object.

illuminated throughout the duration of the model's trial. Then the stimulus was relocated in the same position, and the observer was required to reach to and grasp it when illuminated. The time from the end of the model's movement and the beginning of the observer's movement varied between 1 and 2 s. In all trials the model was present when the observer reached for the target. This condition enabled us to quantitatively measure action priming effects, specifically whether the observer's action was facilitated by the previously observed action of the model.

Gaze condition. This condition was similar in all respect to the 'action' condition except that the model did not move, but was requested to gaze at the stimulus. Nevertheless the observer was still required to grasp the stimulus when illuminated. This condition enabled us to quantitatively measure whether the models' gaze on the stimulus elicited a motor priming effect in the observers.

Control condition. This condition was similar in all respect to the 'gaze' condition except that the model was requested to gaze away from the stimulus. Once again the observer was requested to grasp the stimulus when illuminated. This condition enabled us to quantitatively measure whether any type of gaze information would elicit a motor priming effect.

In summary, trials for the model were of three types: (i) 'action' trials in which the model reached towards and grasped the stimulus; (ii) 'gaze' trials, in which the model simply looked at the target; (iii) 'control' trials, in which the model was standing behind the object performing neither a grasping nor a gazing action. The observer always performed only one type of trial, i.e. reach towards and grasp the stimulus immediately after the model's trial. The model and the observer were requested to reach and grasp the stimulus at a leisurely pace.

The three conditions were administered in counterbalanced blocks. We adopted this strategy to avoid intermingling the 'action' and 'gaze' conditions within the same block, which may have allowed the observer to associate the gaze pattern for the 'action' condition with the gaze pattern in the 'gaze' and 'control' conditions. That is, we wanted to avoid the possibility that priming effects due to gaze observation could have been due to re-enacting the gaze pattern in the action trials. Participants performed 20 trials per block.

2.4. Kinematic recordings

The ELITE motion analysis system (Bioengineering Technology & Systems [BTS]) was used to record movements. Reflective passive markers (0.2 cm diameter) were attached on the (a) wrist-radial aspect of the distal styloid process of the radius; (b) index finger-radial side of the nail; (c) thumb-ulnar side of the nail. The wrist marker was used to measure the reaching component of the action. The markers positioned on the finger and thumb were used to measure the grasp component of the action. Four infrared cameras (sampling rate 100 Hz) placed 120 cm away from each of the four corners of the table captured the movement of the markers in 3D space. Coordinates of the markers were reconstructed with an accuracy of 1/3000 over the field of view. The standard deviation of the reconstruction error was 1/3000 for the vertical (*Y*) axis and 1.4/30 000 for the two horizontal (*X* and *Z*) axes.

2.5. Eye movement video recording

The models' and observers' eye movements were video recorded. An independent judge analyzed the video recordings. This procedure was adopted to be sure that in the 'action' and 'gaze' condition the model was looking at the stimulus and that in the 'control' condition was looking away from the stimulus. Furthermore, this procedure was adopted to make sure that the observer was looking towards the model during the three conditions.

2.6. Data processing

An in-house software package was used to analyze the data and provided a three-dimensional reconstruction of the marker positions as a function of time. The data was then filtered using a finite impulse response (FIR) linear filter (transition band = 1 Hz; sharpening variable = 2; cut-off frequency = 10 Hz). Movement initiation was defined as occurring at the release of a starting switch. Movement end was defined as the time when the fingers closed on the target and there were no further changes in the distance between the index finger and thumb.

On the basis of previous action priming reports (Castiello, 2003; Castiello et al., 2002; Edwards et al., 2003) the dependent variables specifically relevant to test our scientific hypothesis were movement duration and time to peak velocity of the wrist.

2.7. Data analysis

For each dependent variable an ANOVA with group (autistic, controls) as the between-subjects factor and type of condition (action, gaze, control) as the within-subjects factor was conducted. In this analysis only the reach-to-grasp movements performed by the observers was considered. Post hoc comparisons were conducted on the mean values of interest using the Newman-Keuls procedure (alpha level: 0.05).

3. Results

The dependent measures that were investigated showed a significant change in the direction of the experimental hypothesis. The interaction group by type of condition was significant for both movement duration [$F(1,11) = 38.45, p < 0.0001$] and time to peak velocity [$F(1,11) = 48.54, p < 0.0001$]. Post hoc contrasts indicated that the grasping action of the normal children was facilitated by the previously observed action performed by the model (Fig. 2). Facilitation here was defined as a reduction in movement duration and an anticipation of the time to peak velocity. This occurred both when the model performed

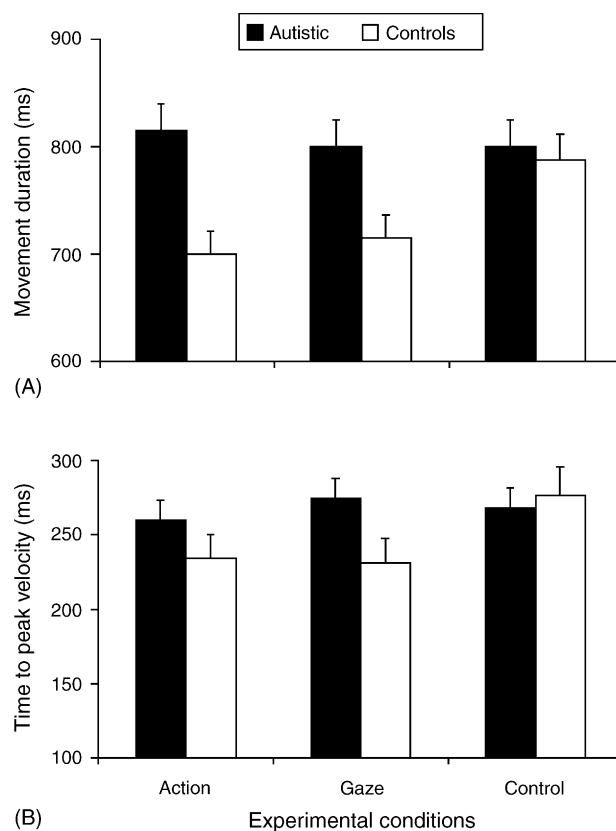


Fig. 2. Graphical representation of the interaction group (autistic, controls) by type of condition (distractor, no distractor) for movement duration (A) and time to peak velocity (B). Action: when the model performed the action. Gaze: when the model did not perform any reach-to-grasp action, but only gazed at the target and distractor. Control: when the model did not perform any reach-to-grasp action and gazed away from the stimulus. ms: milliseconds. Bars represent the standard errors of the means.

the action and when the model simply looked at the stimulus. However, it did not occur when the model looked away from the stimulus (Fig. 2). Importantly, the participants with autism were never affected by observing the model. This was true whether the model actually performed the grasping action, simply gazed at the stimulus, or looked away from the stimulus (Fig. 2). These findings suggest that for normal children the perception of the hand movement prime the action they are subsequently requested to perform, but also that the perception of the gaze of the model provides information about their motor intentions, without the necessity for the model to perform the actual movement. Crucially, the children with autism appeared to be unable to perform such coding. We ascribe this lack of effects to the inability of autistic children to gain any facilitation from the observed action or to infer motor intention and goals from the direction of the model's gaze.

An ANOVA with group (autistic, controls) as between subjects factor and type of condition (action, gaze, and control) as within subjects factor was conducted on the percentage values for the number of times the observer looked at the model during the trials as scored from video recording. The percentage was calculated with respect to the total amount of trials for each condition. No significant differences were found with respect to the participant type. When acting as observers the autistic and the controls both oriented their eyes towards the model equally often (autistic: 98%; controls: 97%) and independently of the type of condition.

4. Discussion

The present study was aimed at determining whether children with high-functioning autism have difficulties in the processing of gaze and whether such a difficulty could be linked with motor behaviour. Our results indicate that gaze processing is dysfunctional in children with high-functioning autism and that this is reflected in their inability to infer and re-enact observed actions. This conclusion was strongly supported by the kinematic data in which facilitation effects on kinematics were not evident for autistic children following the observation of either an overt reach-to-grasp action or the observation of a model simply gazing at an object. However, in line with previous motor priming evidence, we found that normal children showed a reliable priming effect from the prior observation action or gaze trials on the kinematics of reaching towards a stimulus (Castiello, 2003; Castiello et al., 2002; Edwards et al., 2003).

Whereas previously the understanding of the dysfunctional gaze coding in autism had been restricted to propositional mental states (e.g., Baron-Cohen et al., 1995), we have here shown that this deficit extends to motor intentions. This suggests that gaze coding is an integral component in the process of understanding the motor intention behind gaze patterns. Thus, the eyes may act as a natural cue to 'motoric' mentalistic information.

There are however some issues that need clarification before this conclusion can be fully accepted. The first issue concerns the recent observation by Dalton et al. (2005) of a strong correlation between the amount of time adolescents with autism looked directly at the faces in an imaging study (using eye-tracking

methods) and the degree of activation in the fusiform face area. This study showed that children with autism often do not look directly at a face. Thus, it may be hypothesised that the reason why the autistic children in this study were not influenced by the model's movements or gaze may have been simply because they did not look directly at the model during the experiment or monitor her eye gaze.

However, from the analysis of our video recording we were able to ascertain that autistic children looked at the model during the observation phase with particular reference to the face area. In this respect it might be argued that the technique of video recording used in this study was insufficient to determine gaze position within the face of the model. Thus, the fact that autistic subjects looked at the model as much as normals may not mean that they paid attention to the eyes as much. Therefore, although we cannot exclude that the autistic subjects inspected the eyes of the model less than the healthy volunteers, the time spent inspecting the face was similar.

Nevertheless, a number of previous studies testing the hypothesis that eye processing abnormalities in autism are related to a more general deficit in face processing showed that this may not be the case. For example, children with autism can recognise identity and gender from photographs of the face alone and can recognise emotional expressions in the face (Baron-Cohen, Spitz, & Cross, 1993). However, they do seem to make less use of the eye region in making facial identity judgements (Langdell, 1978). This latter anomaly simply confirms that they are not making use of the eyes in the same way as do normal children. Further, in all three conditions of the present study the face of the model was present. What differed was the model's intentional attitude towards the object. When no intentional link was present between the gaze and the object, as in the control condition, the normal children showed the same pattern as the autistic children even though the model's face was available. In sum, although the possibilities that the reported effects are caused by generalised abnormalities in face processing and lack of attention to the model might be ruled out, whether the reported finding is due to differences in eye-inspection remain for future investigations.

A second issue is related to an alternative explanation which may account for the findings on the normal children. It may be hypothesised that when the action of the model was not available, the model's motor intentions were inferred from gaze by associating the pattern of gaze observed in the gaze condition with that already experienced when observing the model grasping the object. In such hypothesis, the deficit observed in autistic children would not be a deficit of intention coding, but simply a deficit of association. This interpretation, however, is unlikely given that, if this were the case, the reported priming effect on the normal children would have been present in all conditions, control condition included. This is because whereas the control condition included both the model's eyes and the object, the model's gaze was directed away from the object. Further, the 'action' and 'gaze' experimental blocks were counterbalanced so that the timing of exposure to the 'action' condition was controlled for. Thus, if the mere presence of the object together with any kind of gazing were sufficient to cause such facilita-

tion effects, then similar effects in the control conditions should have been found. However, this was not the case allowing us to disregard such alternative explanation.

A third issue is concerned with the fact that observers watched an actor grasping an object and then waited till the object was illuminated at a variable interval from 1 to 2 s after the actor completed the action. It might well be that autistic children do show priming effects, albeit priming effects that have abnormal temporal characteristics. For example, priming in autistics might either have a shorter duration or a longer latency than normal. We tackled this issue analysing separately the subset of trials in which the stimulus/response interval was short (around 1 s) versus those in which it is longer (around 2 s). The results for this analysis were not significant. Thus, the length of the stimulus/response interval used here seem not to play a pivotal role in determining the reported effect. However, we cannot exclude the possibility that if priming is highly refractory, priming effects might have been observed had the intervals been even longer.

Considering these findings in the light of recent discoveries in neurobiology offers the prospect for a new speculative interpretation of the link between the coding of gaze and the reading of another person's motor intention. For example, recent neuroimaging evidence suggests that in humans specialised mechanisms might be engaged in the ability to understand the intentions of others from watching their actions (Ramnani & Miall, 2004). In particular the so called 'mirror' system (Rizzolatti, Fogassi, & Gallese, 2001) seems to be involved in this capacity (Becchio, Adenzato, & Bara, 2005).

Mirror neurons fire when the monkey performs a grasping action, but also when the animal observe somebody else, performing the same action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti et al., 2001). Two major areas containing mirror neurons have been identified so far, area F5 in the inferior frontal cortex and area PF/PFG in the inferior parietal cortex. Inferior frontal and posterior parietal human areas with mirror properties have also been described (Buccino et al., 2001; Decety & Grezes, 1999; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). Importantly, these areas are intimately connected with the superior temporal sulcus (STS) an area which has been proposed to be fundamental for the perception and interpretation of gaze (Allison, Puce, & McCarthy, 2000; Puce, Allison, Bettin, Gore, & McCarthy, 1998). As recently proposed, taken together these areas form a system underlying the understanding of observed actions (Keysers & Perrett, 2004).

Crucially, in autistic people, bilateral anatomical abnormalities localized in the STS and 'mirror' areas have been reported (Boddaert et al., 2004; Pelphrey, Adolphs, & Morris, 2004; Waiter, Williams, Murray, Gilchrist, Perrett, & Whiten, 2005a, 2005b). Consequently it has been proposed that some dysfunction in the mirror system might be implicated in the constellation of clinical features which constitute the autistic syndrome (William, Whiten, Suddendorf, & Perrett, 2001). To support this hypothesis recent evidence reported consistent neurobiological impairments within the mirror system of autistic individuals (Oberman et al., 2005). In this study 'mu' wave suppression over sensorymotor cortex, a marker of mirror neuron activity, was measured while participants (autistic and control subjects)

observed both their own actual movements and movements performed by others. The results indicated that autistic individuals showed 'mu' wave suppression only to self-performed movements but not to the same movements performed by others.

Assuming that the mirror circuit including STS is dysfunctional in people with autism may explain why we did not find facilitation effects for both the gaze and the action conditions for this group. For the 'action' condition abnormal activation of the mirror system may have not allowed a proper matching between the observed action and the subsequent to-be-performed action. In turn this would have prevented the beneficial effects of action priming. For the 'gaze' condition, the abnormal activation of the mirror system, in terms of intentional coding, together with abnormal activation of the STS area, which is necessary for gaze coding, would have prevented the coding of motor intention from gaze.

In summary, high-functioning children with autism showed significant abnormalities in the use of gaze direction as a cue for reading motor intentions. In contrast, normal children do use gaze direction to infer motor mental states of others. These findings are testimony that gaze encoding abnormalities in autism may determine the failure to use gaze as a critical piece of information regarding another person's motor intentions.

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