Motor contagion from gaze: the case of autism

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It has been proposed that motor contagion supplies the first step in mentalizing. Here, by using kinematic methods, we show that in contrast to normally developing children, children with autism seem to be immune to motor contagious processes. In the main experiment, involving twelve high-functioning autistic children (six males and six females, 10–13 years old, mean 11.1 years) and 12 normally developing controls (age and gender matched), two participants, a model and an observer, were seated facing each other at a table. The model was a normally developing child but the observer was either a normally developing or autistic child. The model was requested to grasp a stimulus or simply to gaze towards the target which could be presented alone or flanked by a distractor object. After watching the model, the observer was asked to grasp the object (always in the absence of the distractor). Despite the distractor being removed, the kinematics of normally developing children was affected by having observed an action performed in the presence of a distractor, thus revealing a transfer of interference from the model's action. Consistent with prior evidence, this transfer of interference effect was also present when the model simply looked at the target in the presence of the distractor object. In contrast, autistic children did not show any interference effect either from action or from gaze observation. A control experiment explored the importance of the information coming from the model's gaze pattern in eliciting the effects of motor contagion in normally developing children. In this case, the model was asked to fix their eyes on the target despite the presence of the distractor. Results highlight the importance of gaze direction in motor contagion, demonstrating that in normal children blocking the gaze prevented the transfer of interference. Altogether, these findings suggest that eye gaze plays a central role in eliciting motor contagion. We discuss these results in light of the deficit exhibited by children with autism in reading intentions from gaze.

Introduction

To understand what another person has in mind to do, we do not need her to complete the action. Often, we do not even need her to begin acting: we can read motor intentions in her eyes in advance.

How can we do that?

Evidence that under specific circumstances motor intentions can be read from gaze comes from studies adopting interference paradigms. Several experiments provide evidence that implicit processing of distractor objects can 'interfere' with the action to a relevant target (for a review, see Castiello, 1999). In a series of experiment, Castiello (2003) investigated whether motor interference may

transfer to an observer required to perform a similar action. Participants observed a human model reaching and grasping for an object presented in isolation or flanked by a smaller or larger object (distractor). Subsequently, the distractor object was removed and participants were required to perform a similar action towards the target object. Despite the distractor being removed, kinematics of both the human actor and the observer were affected by the presence of the distractor. Crucially, similar effects were found in the observer's kinematics during the trials in which the actor—seated in front of the observer—simply looked at the distractor object. Observing a model gazing at a distractor object produced in the observer the same type

of motor interference that produced when observing the model executing an interfered action. No transfer of interference was observed when the model was asked to fixate the target (constrained vision) while performing the reach-to-grasp action.

These findings suggest that that it is through eye gaze that transfer of interference takes place: even in the absence of any overtly executed action, perception of the movement of the eyes of the model has measurable effects on the agent's kinematics. This transfer of interference can be interpreted as a form of 'motor contagion' operating through eye gaze (Blakemore and Frith, 2005): the motor intention read in the model's gaze affects the observer's action.

The goal of the present study was to ascertain whether motor contagion by gaze also arise in autistic children. Children with autism clearly possess the basic knowledge about eyes and seeing. For example, they understand that eyes are for seeing (Tan and Harris, 1991) and are also able to judge where another person is looking (Baron-Cohen, 1995; Leekam *et al.*, 1998). Nevertheless, they do not look at faces in the same way as normal children do (e.g. Dawson *et al.*, 2002). For typically developing individuals, eye direction conveys key social information, such as personal interest and attentional engagement. Despite their ability to perceive gaze direction and detect contingencies between direction of gaze and location of targets in space (Ristic *et al.*, 2005), children with autism show marked difficulties in monitoring gaze in unstructured situations and fail to use gaze directions to infer another's goals, desires and points of interests (Baron-Cohen *et al.*, 1995; Dawson *et al.*, 1998; Leekam *et al.*, 1998). It has been proposed that this failure reflects impairment in the ability to empathize (Baron-Cohen, 1995, 2003, 2005). According to this view, autistic children lack the ability to attribute mental states to themselves and others and this might explain why they are unable to infer other persons' mental states from gaze.

In this study, we ask whether abnormalities in motor contagion may contribute to this failure, preventing intentional gaze processing in autism. Motor contagion has been proposed as the first, basic step in mentalizing, providing an automatic mechanism to access another person's intention (Blakemore and Frith, 2006; Frith, 2007). In this view, contagion would bring the observer one step closer to the actor so that she would be in an ideal starting point as to predict the actor's next action. Evidence from developmental science suggests that this mechanism emerges early in life (Meltzoff and Gopnik, 1993), providing typically developing infants with an enormous leverage for social cognitive development (Meltzoff, 2005). Because humans' acts are seen in others and performed by the self, the infant can grasp that the other is at some level 'like me'. This basic equivalence provides the infant with a framework for understanding the meaning that lays behind the movements performed by others (Meltzoff, 2007).

Table I Participant demographics for children with autism participating in the study

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

[a]Total score of 30–37 = mild autism.
CARS, Childhood Autism Rating Scale.

There are, thus, substantial reasons for considering contagion as a prime candidate for the building of a theory of others mind. A natural question is whether the impairments exhibited by autistic children in understanding the psychological states of others may stem from deficiencies in contagious processes. The main experiment of the present work was specifically designed to test whether motor contagion operates in autistic children through eye gaze. If a motor contagion impairment in autism is demonstrated, then this may explain why autistic children appear blind to the mental significance of other persons' gaze. High functioning autistic children were asked to grasp a single target object immediately after having observed another individual either grasping or simply looking at the same target object flanked by a distractor. If motor contagion is defective in autism, no transfer of motor interference—either from action or gaze—should be observed.

Main experiment
Methods

Participants
Twelve high-functioning autistic children (six males and six females, 10–13 years old, mean 11.1 years) and 12 normally developing 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. A normally developing 12-year-old child acted as a model. All children were right-handed, reported normal or corrected-to-normal vision and no-hearing impairments, and were naive as to the purpose of the experiment. None were on medication or exhibited praxis problems as assessed by an occupational therapist. The children with autism 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; see Table 1). The Childhood Autism Rating Scale (CARS) (Schopler *et al.*, 1993) had been administered at the ages of 4–8 years by an experienced clinical psychologist.

Further tools for diagnosis were the Autism Diagnostic Interview-Revised (ADI-R; Lord *et al.*, 1994) and the Autism Diagnostic Observation Schedule (ADOS; Lord *et al.*, 2000). At the time of the experiment, all of the children with autism were attending special education classes for autism.

Materials

Stimuli were cylinders made of a translucent material and consisted of (i) a 3D target object (diameter: ∼4 cm; see Fig. 1A) positioned at a distance of 30 cm from the hand starting position along the mid-sagittal plane; (ii) a 3D distractor object of a larger size as the target (large size distractor; diameter: ∼6 cm; see Fig. 1B); (iii) a 3D distractor object smaller than the target (small distractor; diameter: ∼1 cm; see Fig. 1C). In order to illuminate the stimuli, three LEDs were embedded in the working surface underneath both the target and large size distractor
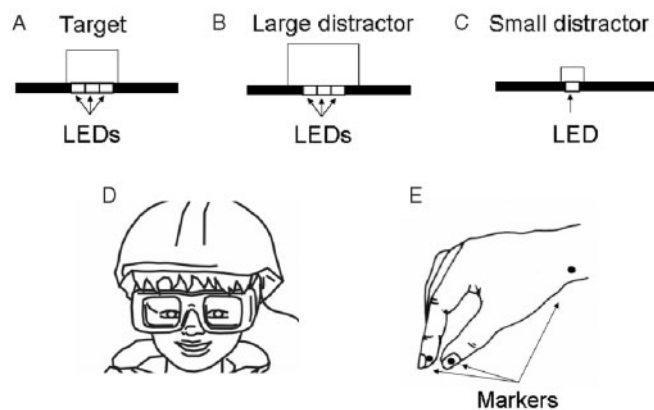
Fig. I Graphical representation of the type of stimuli. Stimuli were cylinders made of a translucent material and illuminated by LEDs embedded in the working surface. The target cylinder (**A**) and the large size distractor cylinders (**B**) were illuminated by three LEDs. Underneath the small distractor cylinder (**C**) was one LED. (**D**) Participants wore lightweight spectacles, containing liquid crystal lenses which changed from opaque to clear on computer's signal. For the sake of comfort, the spectacles were attached to an helmet. (**E**) Reflective passive markers were attached on the wrist—radial aspect of the distal styloid process of the radius, index finger—radial side of the nail and thumb—ulnar side of the nail.

cylinders (Fig. 1A and B). Underneath the small distractor cylinder was one LED (see Fig. 1C). The LEDs were connected to two metallic contacts on the exterior of the cylinders. These contacts met with three other metallic plates (one to the right, one in the centre, one to the left) which were fixed to the table and connected to a PC. The distractor object was presented at 20° to the right or left of the target. To govern the visual availability of the target and distractor stimuli, participants (both models and observers) wore lightweight spectacles (Fig. 1D; Plato Technologies Inc.), containing liquid crystal lenses, that changed from opaque to clear on computer's signal. The distractor object was presented at 20° to the right or left of the target (Fig. 2A and C).

Kinematic recordings

The ELITE motion analysis system (Bioengineering Technology & Systems [B|T|S|]) was used to record movements. Reflective passive markers (0.2 cm diameter) were attached on the (i) wrist—radial aspect of the distal styloid process of the radius; (ii) index finger—radial side of the nail; (iii) thumb—ulnar side of the nail (Fig. 1E). 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 SD 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.

Data processing

An in-house software package was used to analyse the data and provided a 3D reconstruction of the marker positions as a function of time. The data were then filtered using a finite impulse response (FIR) linear filter (transition band = 1 Hz; sharpening variable = 2; cut-off frequency = 10 Hz). The wrist marker was used to measure the reaching component of the action. The markers positioned on the index finger and thumb were used to measure the grasp component of the action. The dependent variables that were thought to be specifically relevant to the hypothesis under test were (i) movement duration, (ii) deceleration time of the arm and (iii) amplitude of maximum grip aperture. Movement duration was calculated as the time between the release of a starting switch and the time at which the participant's fingers closed upon the object. Deceleration time was calculated as the
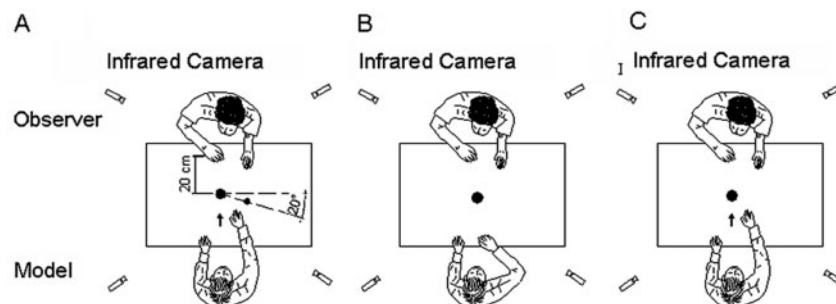
Fig. 2 Graphical representation of the experimental setup. Panel '**A**' shows the model reaching towards and grasping the object while being watched by the observer. Panel '**B**' shows the experimental setup for the observer's trial. Panel '**C**' shows the observer performing the same reach-to-grasp movement after having observed the model acting upon the object. Filled arrows indicate the subject who is reaching towards the object.

Table 2 Mean ($\pm$SD) of kinematic parameters with respect to the type of experimental condition for the human model

Experimental condition	No distractor	Small distractor	Large distractor	Statistical values
Movement duration (ms)	801 ($\pm$75)	874 ($\pm$86)	768 ($\pm$ 67)	$F_{(1,9)} = 48.32$, $P < 0.0001$; $\eta^2 = 0.873$
Deceleration time (ms)	63 ($\pm$8)	75 ($\pm$6)	57 ($\pm$ 5)	$F_{(1,9)} = 58.43$, $P < 0.0001$; $\eta^2 = 0.732$
Amplitude of max grip aperture (mm)	52 ($\pm$3)	48 ($\pm$2)	60 ($\pm$ 3)	$F_{(1,9)} = 31.09$, $P < 0.0001$; $\eta^2 = 0.821$

Notes: ms = milliseconds; mm = millimetres.

time from peak velocity to the end of the movement. The amplitude of maximum grip aperture was calculated as the maximum distance reached during the movement by the two markers positioned on the index finger and the thumb.

These dependent variables were chosen because consistent results within the reach-to-grasp literature have shown that the reach-to-grasp movement is dependent upon the size of the stimuli. In particular, movement duration is longer, deceleration time (the time from the moment of peak velocity to the end of the movement) is prolonged, and the amplitude of the maximum grip aperture is reduced for smaller than for larger stimuli (e.g. Jakobson and Goodale, 1991). Thus, in a movement towards a large target, if the results showed either a longer movement duration, or a prolonged deceleration time, or a lowered maximum grip aperture in the presence of a smaller distractor, inferences regarding the influence of the small distractor on the kinematics of both the actor and the observer for movements towards the larger target could be advanced (Castiello, 2003).

Procedure

Two participants, the model and an observer, were seated facing each other at a table. Artificial lighting within the room allowed the model and the observer to see each other and the experimental setup clearly. 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 midline. The spectacles of both the observer and the model cleared and the target (or both the target and the distractor) were illuminated. In the 'action' condition, the model reached towards and grasped the target (Fig. 2A). Then the observer's spectacles were shut and the experimenter removed the distractor object (Fig. 2B). After this operation lasting ∼1 s, the observer's spectacles were re-opened and he/she was required to reach and grasp the target object positioned in front of him/her (Fig. 2C). For the observer's trial, there was always only 'one' object presented. In the 'gaze' condition, the model did not move the arm, but he/she was free to move the eyes. The observer was still required to grasp the target object after the spectacles had re-opened. The order of conditions was counterbalanced between participants. For the 'action' condition, the model performed 50 randomized trials in which all possible target–distractor size/location combinations (10 trials for each combination) were presented: (i) no distractor; (ii) left-small distractor; (iii) right-small distractor; (iv) left-large distractor and (v) right-large distractor. The observer performed 50 trials towards the target always in the absence of the distractor. For the 'gaze' condition, the same conditions and the same number of trials were administered to the model, but she did not perform any reach-to-grasp action. She simply looked at the scene.

The observer performed 50 trials as for above. The experimental session lasted ∼1 h.

Data analysis

For each of the considered dependent measures, a repeated-measures analysis of variance (ANOVA) with group (autistic, controls) as a between-subjects factor and type of observed behaviour (action, gaze) and type of observed trial (no distractor, small distractor, large distractor) as within-subjects factors was conducted. This analysis allowed to evaluate the effect of observing the model acting or gazing upon the target on the kinematics of the subsequent action performed by the observer and possible differences between the two groups. To evaluate a possible effect of distractor location, preliminary analyses considering position (right or left) as within-subjects factor position were performed. No effects due to distractor location were found. Therefore, values for right and left distractors have been collapsed. An additional ANOVA with type of trial (no distractor, large distractor, small distractor) was carried out to evaluate the effect of the distractor on the kinematics of the model for the action condition. Table 2 reports the means and statistical values for the dependent measures concerned with the model's movement. The dependent measures that were investigated showed the classic interference effects of distractor size on movement kinematics as described above (e.g. Castiello, 2003).

Eye movement recording and analysis

Participants' eye movements were monitored on-line, recorded and subsequently evaluated by an independent rather which was naïve as to the purpose of the experiment. This procedure was adopted to be sure that during each trial both the model and the observer were gazing at the scene and that the observer was paying attention to the model's gaze. The criteria for evaluation included the monitoring during the trial of gaze direction towards, the face/eyes, the trunk, the moving arm of the model and the stimuli. Trials in which the observer gazed away from the area including the model and/or the stimuli were discarded and subsequently repeated.

Eye movements for the model were analysed by evaluating the percentage values for the number of times the model looked at both the target and the distractor (when present) during the trials (as scored from video recording) by means of an ANOVA with type of trial (no-distractor, small distractor, large distractor). To evaluate the percentage values for the number of times the observer looked at the model's gaze during the observation phase of the trial, as scored from video recording, a repeated-measures ANOVA with group (autistic, controls) as a between-subjects factor, and type of observed behaviour (action, gaze) and type of trial (no distractor, small distractor, large distractor)
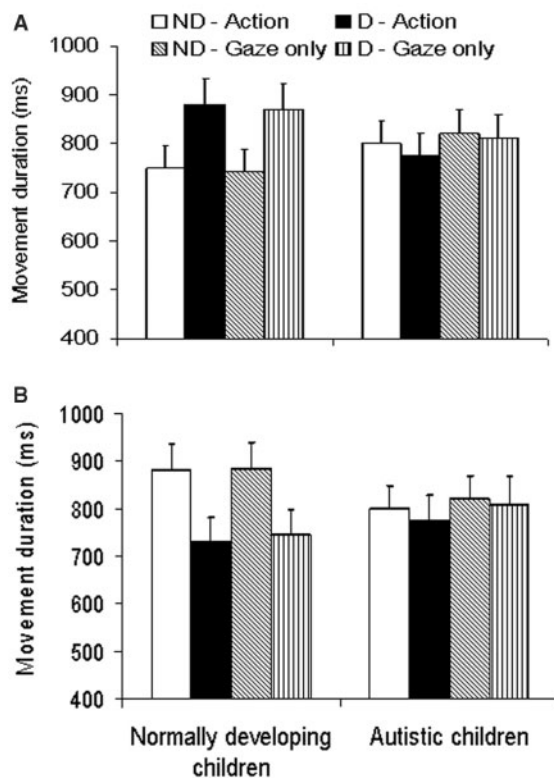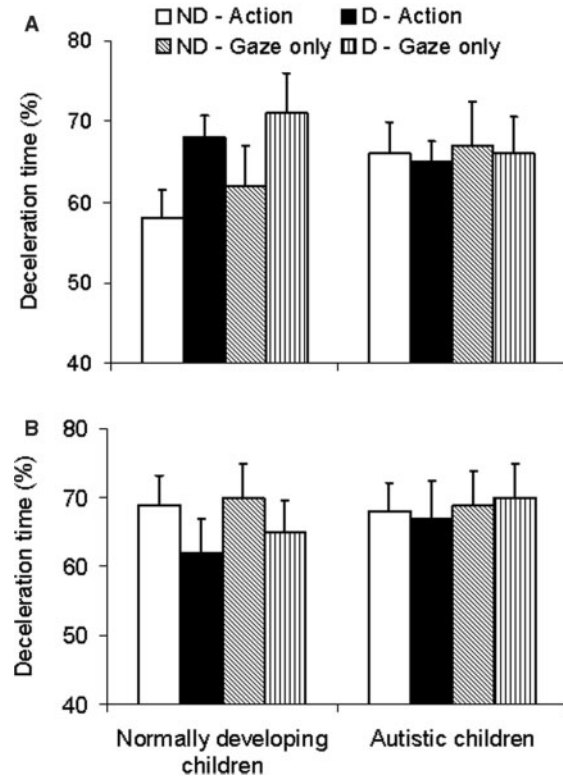
Fig. 3 Main experiment. Graphical representation of the interaction Group (autistic, controls) × Type of observed behaviour (action, gaze) × Type of trial (no distractor, small distractor, large distractor) for movement duration. Panel '**A**' represents movements directed towards the target in the presence of the small distractor. Panel '**B**' represents movements directed towards the target in the presence of the large distractor. D: distractor. ND: no distractor. 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. ms: milliseconds. Bars represent the SEM.

as within-subjects factors was performed. Bonferroni corrections were applied (alpha level 0.05).

Results

The interaction Group × Type of observed trial was significant for movement duration [$F(1,11) = 17.25$, $P < 0.001$; $\eta^2 = 0.570$], deceleration time [$F(1,11) = 10.07$, $P < 0.001$; $\eta^2 = 0.500$] and amplitude of maximum grip aperture [$F(1,11) = 36.12$, $P < 0.0001$; $\eta^2 = 0.675$]. For normally developing children, the observed pattern of results mirrored that obtained in previous studies with neurologically healthy adults. Movement duration and deceleration time were longer ($Ps < 0.01$; Figs 3A and 4A, respectively) and amplitude of maximum grip aperture was smaller ($P < 0.01$; Fig. 5A) when the action was performed after observing the model grasping the target in the presence of the small distractor than in the absence of a distractor. Conversely, movement duration and deceleration time were shorter ($Ps < 0.01$; Figs 3B and 4B, respectively) and

Fig. 4 Main experiment. Graphical representation of the interaction Group (autistic, controls) × Type of observed behaviour (action, gaze) × Type of trial (no distractor, small distractor, large distractor) for deceleration time. Conventions as for Fig. 3.

amplitude of maximum grip aperture was larger ($P < 0.01$; see Fig. 5B) when the action was performed after observing the human model grasping the target in the presence of the large distractor than in the absence of a distractor. This set of results applied to both the action condition and the gaze condition (lack of significance for the interaction type of trial by type of observed behaviour). Importantly, for the autistic children, the pattern described above was not revealed. Movement duration, deceleration time and amplitude of maximum grip aperture remained similar independently from the presence or absence of the distractor in both the action and the gaze condition (Figs 3–5).

Eye movement pattern

The pattern of the model's gaze differed with respect to the presence or absence of the distractor and the experimental condition. For the 'action' condition, when the distractor was not present, the model's gaze was mostly directed towards the target and in some occasions shifted from the performing arm to the target. When the distractor was present, the model often disengaged gaze from the target and moved it towards the distractor during the action. For the 'gaze' condition, the difference in the model's direction of gaze depending on the presence or absence of the

distractor was much more evident than for the 'action' condition. When the distractor was present, the model switched gaze from the target to the distractor for almost all 'distractor' trials (97% of trials).

No significant differences were found between normally developing children and autistic children in the percentage of gaze shifts towards the model during the model's trials. Normally developing children looked towards the eyes of the model in 84% of the trials for the 'action' condition and in 97% of trials for the 'gaze' condition. A similar gaze pattern was found for the autistic children. They attended at least once to the model's gaze in 85% of trials for the 'action' condition and in 94% of the trials for the 'gaze' condition. For the 'action' condition, both groups exhibited a pattern of gaze which included (apart looking at the model's eyes) looking at the arm performing the movement, the face and the trunk. For the 'gaze' condition a similar pattern as for the 'action' condition was noticed, but gaze shifts to the resting arm and the trunk were less evident.

Discussion

Results in normal children replicated prior evidence: grasping movement to the target varied with respect to
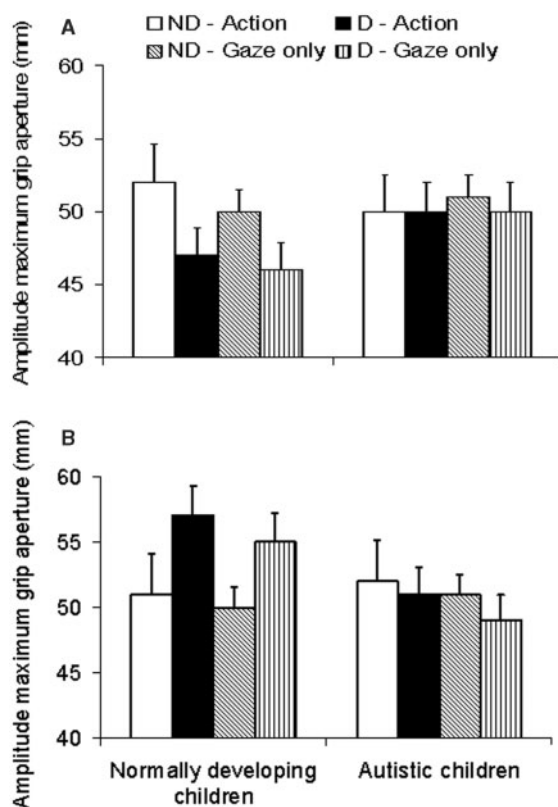
Fig. 5 Main experiment. Graphical representation of the interaction Group (autistic, controls) × Type of observed behaviour (action, gaze) × Type of trial (no distractor, small distractor, large distractor) for the amplitude of maximum grip aperture. Conventions as for Fig. 3.

whether they observed the human model grasping the target in the presence or in the absence of distractor stimuli. Consistent with Castiello (2003), these transfer of interference effects were also present when the model simply looked at both the target and the distractor objects. Autistic children did not show any interference effect either from action or from gaze observation.

The analysis of eye movement video recording suggests that this lack of effects was not due to the fact that children with autism did not look directly at the model during the experiment. As demonstrated, no significant differences were found between normally developing children and autistic children in the percentage of gaze shifts towards the model's face during the model's trials.

Recent studies of face processing have produced differing accounts of how and whether children with autism differ from their typically developing peers on task performance (Jemel *et al.*, 2006; Sasson, 2006). Although many studies have reported abnormalities in the scanning of faces (e.g. Klin *et al.*, 2002*a*; Pelphrey *et al.*, 2002), several others have failed to find differences at a behavioural level (e.g. van der Geest *et al.*, 2002). A reconciling view has been provided by Speer *et al.* (2007). They found that individuals with autism differed from typically developing peers for observation of social scenes showing interactions between two or more characters, but not for observation of a single individual acting in isolation, as occurs in the present experiment.

From a neural perspective, converging evidence indicates that, despite the performance on the task might be as accurate as that of typically developing individuals, the way autistic children processes faces (Schultz *et al.*, 2000) and gaze (Pelphrey *et al.*, 2005) is profoundly abnormal (see Klin *et al.*, 2002*b* for review). This abnormality does not appear to be due to problems with visual discrimination (e.g. Chawarska *et al.*, 2003) or overall cognitive abilities (Klin *et al.*, 1999). Rather, it has been proposed that this deficit may reflect a disconnection between the perceptual processing of gaze and its connection with a mentalistic significance (Pelphrey *et al.*, 2005). The present result adds to these findings suggesting that, in contrast to typically developing peers, children with autism are immune from contagious processes from eye gaze as revealed by kinematics. If contagion supplies the first step in mentalizing, this in turn, may explain why children with autism fail to understand the mental states and intentions of other people on the basis of information gathered from the eyes (Baron-Cohen, 1995; Leekam *et al.*, 1998; Baron-Cohen *et al.*, 1999; Pelphrey *et al.*, 2005).

In this view, gaze direction appears to be crucial as to elicit motor contagion in typically developing children. To further explore this hypothesis we designed a control experiment, in which the model maintained her gaze fixed on the target. We reasoned that if it is through gaze direction that transfer of motor interference occurs in

normal developing children, then blocking gaze on the target should annul or decrease such effect.

Control experiment

The control experiment was similar to the main experiment except for the following aspects: (i) only normally developing children were tested; and (ii) a set of conditions was added in which the model was asked to maintain the gaze fixed on the target independently of the presence of the distractor object. If gaze direction is crucial in determining motor contagion (in terms of transfer of interference), then no such effect should be found in normally developing children when the model maintains her eyes stationary on the target.

Methods

Participants

Twelve 12 normally developing children (six males and six females, 10–13 years old, mean 12.1 years) with the same characteristics as those utilized in the main experiment participated in this control study (see Table 1). A normally developing 12-year-old child acted as a model.

Materials and procedure

Materials and procedure were the same as those for the main experiment except that there were two sets of conditions: 'free-gaze' conditions and 'blocked-gaze' conditions. In free-gaze conditions, the model was allowed to gaze about freely as in the main experiment. In blocked-gaze conditions, the model was requested to maintain the eyes fixed on the target independently from the presence/absence of the distractor. Specifically, for the 'free-gaze' action condition, the model performed 50 randomized trials in which all possible target–distractor size/position combinations (10 trials for each combination) were presented: (i) no-distractor; (ii) left-small distractor; (iii) right-small distractor; (iv) left-large distractor and (v) right-large distractor. The observer performed 50 trials towards the target always in the absence of the distractor. For the 'free-gaze' gaze only condition the same number of trials were performed by the model, but she did not perform any reach-to-grasp action. She simply looked at the scene. The observer performed 50 trials as per the action condition. The 'blocked-gaze' set of conditions was similar to the 'free-gaze' set except that the model maintained the eyes fixed on the target independently from the presence of the distractor. The model's eyes were monitored on-line. Trials in which eye movements occurred during the trial were discarded and replaced.

Data analysis

Preliminary analyses as to test for the effect of the distractor on the kinematics of the model and for distractor location were conducted. The results for these preliminary analyses mirrored those obtained for the main experiment. In order to evaluate whether there were differences between the free- and blocked-gaze conditions for each of the dependent measures (the same as those analysed for the main experiment), a repeated-measures analyses of variance (ANOVA) with type of gaze (free, blocked), type of observed behaviour (action, gaze) and type of observed trial

(no distractor, small distractor, large distractor) as within-subjects factors was performed. Bonferroni corrections were applied (alpha level 0.05).

Results

The interaction between Type of gaze × Type of observed trial was significant for movement duration [$F(1,11) = 26.12$, $P < 0.0001$; $\eta^2 = 0.542$], deceleration time [$F(1,11) = 18.31$, $P < 0.0001$; $\eta^2 = 0.641$] and amplitude of maximum grip aperture [$F(1,11) = 10.04$, $P < 0.001$; $\eta^2 = 0.555$]. Movement duration and deceleration time were longer ($Ps < 0.01$; Figs 6A and 7A) and the amplitude of maximum grip aperture was smaller ($P < 0.01$; see Fig. 8A) when, during the model's trial, the target was presented with the small distractor rather than with no distractor. Conversely, movement duration and deceleration time were shorter ($Ps < 0.01$; Figs 6B and 7B) and the amplitude of maximum grip aperture was larger ($P < 0.01$; Fig. 8B) when the action was performed after observing the human model grasping the target in the presence of the large distractor than in the absence of a distractor. Crucially, this set of results applied only for the free-gaze condition (Figs 6–8). For the blocked gaze conditions, no
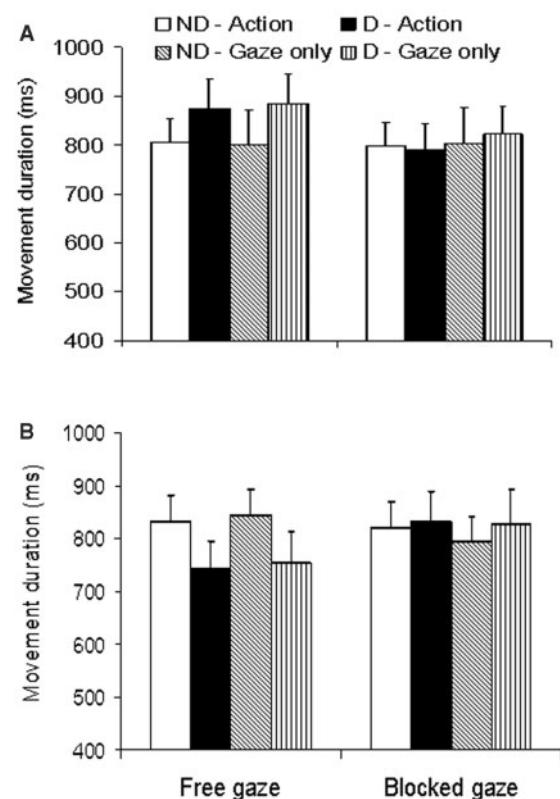
Fig. 6 Control experiment. Graphical representation of the interaction Type of gaze (free gaze, blocked gaze) × Type of observed behaviour (action, gaze) × Type of trial (no distractor, small distractor, large distractor) for movement duration. Conventions as for Fig. 3.

significant differences were found depending on the presence/absence of the distractor.

Discussion

The results of the control experiment highlight the importance of gaze direction in motor contagion: in absence of gaze direction information transfer of interference disappears in normal children. In line with Castiello (2003), this result suggests interference transfer does not arise from the processing of eye gaze *per se*, but from using gaze as to 'infer' another individual's motor intention.

This conclusion is consistent with previous evidence concerning facilitation effects (Pierno *et al.*, 2006a). Participants grasped a stimulus after having watched the model either grasping the stimulus, watching the stimulus or gazing away from the stimulus. Normal children showed facilitation effects in terms of movement speed following the observation of the model grasping or gazing at the object. No evidence of facilitation was found when the model's gaze was not directed at the object. Interference effects in the present experiment show a similar trend. That is, to reveal an interference transfer it is not sufficient that the model's eyes and the distractor object are simultaneously visible by the observer. It is only when the model gazes at the distractor object, that the observer establishes a

connection between the two. Preventing such connection by blocking gaze annuls the effect of the distractor on the kinematics of the observer.

General discussion

Autism has been universally and characteristically described as a dysfunction in 'cognitive empathy', i.e. the ability to represent the thoughts, desires and beliefs of others (Blair, 2005). The possibility that other forms of empathy may be dysfunctional in autism has only recently been considered. In this respect, the revised model of empathizing theory of autism proposed by Baron-Cohen (2003, 2005) holds that alongside their deficit in cognitive empathy, individuals with autism may have delays and difficulties in the developing of 'emotional empathy', i.e. in reacting to another's emotional state.

The present results support the notion that a third form of empathy may be compromised in autistic children, i.e. 'motor empathy'. Motor empathy has been defined as the tendency to automatic mimic and synchronize facial expressions, vocalizations, postures and movements with those of another person (Hatfield *et al.*, 1994).
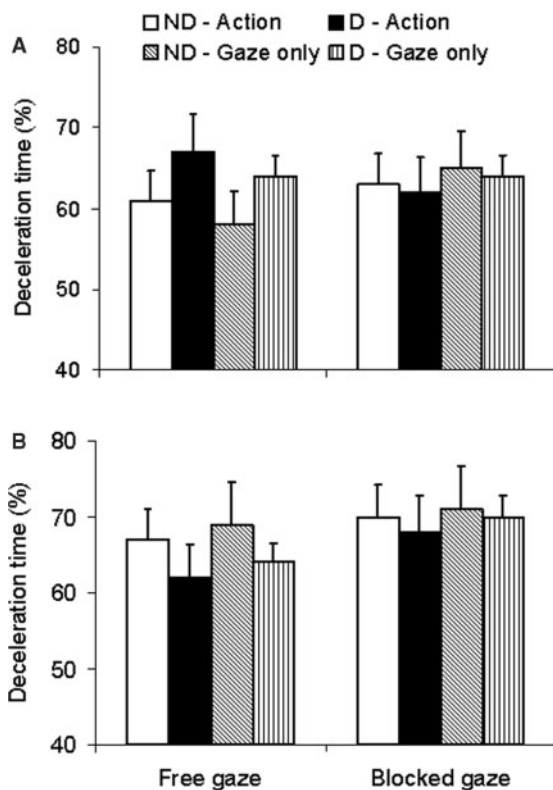
Fig. 7 Control experiment. Graphical representation of the interaction Type of gaze (free gaze, blocked gaze) × Type of observed behaviour (action, gaze) × Type of trial (no distractor, small distractor, large distractor) for deceleration time. Conventions as for Fig. 3.
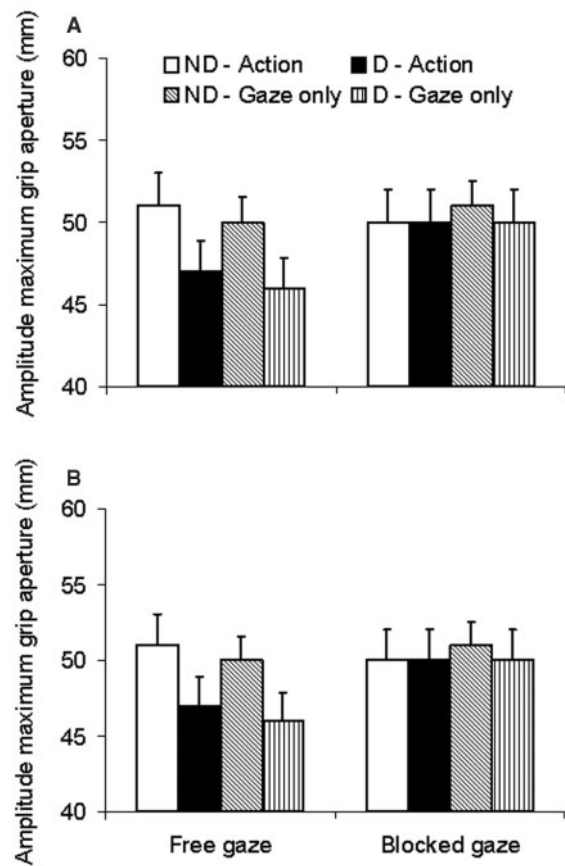
Fig. 8 Control experiment. Graphical representation of the interaction Type of gaze (free gaze, blocked gaze) × Type of observed behaviour (action, gaze) × Type of trial (no distractor, small distractor, large distractor) for the amplitude of maximum grip aperture. Conventions as for Fig. 3.

The behavioural effects observed in the present study may be interpreted as a gaze-related, 'motor empathy' dysfunction. Whereas the kinematics of normal children are automatically affected by the gaze of others, no transfer of motor interference is observed in children with autism. Their kinematics appears immune to any social influence. Why might this be?

Although the present study does not provide direct information about brain activity, we speculatively suggest that this deficit may reflect a breakdown between the neural structures necessary to perceive another person's gaze direction, including the posterior superior temporal sulcus (pSTS) (for review see Pelphrey and Morris, 2006), and those necessary to mirror other persons' motor actions, including the premotor cortex, the inferior frontal gyrus and the inferior parietal lobule (for review see Rizzolatti *et al.*, 2001; see also Gallese, 2004). Converging evidence from neuroimaging studies suggests that in neurologically normal individuals these structures form a functional circuit—an action observation system—underlying the understanding of other persons' intentional actions (Frith, 2007; but see also Decety *et al.*, 1997; Decety and Grezes, 1999; Keysers and Perrett, 2004). Indirect evidence that this network of areas may be involved in transfer of interference has been recently provided by two functional magnetic resonance imaging (fMRI) studies. For one, it has been demonstrated that these areas are sensitive to the presence of a distractor object (Pierno *et al.*, 2006*b*). For the other, it has been demonstrated that observing a human model gazing at an object recruits in the observer the same areas elicited by the observation of a grasping action on the same object (Pierno *et al.*, 2006*c*).

Consistent with the proposal of a failure to read motor intention from gaze, several studies have revealed anatomical (Boddaert *et al.*, 2004; Waiter *et al.*, 2005*a*, *b*; Hadjikhani *et al.*, 2006) and functional abnormalities (Castelli *et al.*, 2002; Nishitani *et al.*, 2004; Oberman *et al.*, 2005; Pelphrey *et al.*, 2005; Theoret *et al.*, 2005; Dapretto *et al.*, 2006; Williams *et al.*, 2006) in the action observation system in autism. For example, functional abnormalities in the pSTS have been revealed in response to viewing gaze shifts (Pelphrey *et al.*, 2005). Whereas neurologically normal subjects showed pSTS activity that differentiated goal-directed shift and non-goal-directed shifts, in subjects with autism pSTS activity was not modulated by the context of the perceived gaze shifts. Gallese (2006) proposed that mirror neurons dysfunction, causing defective intentional attunement, may explain some of the social impairments observed in autistic children. Evidence of mirror neurons dysfunction in autism has been provided using electroencephalography (EEG) (Oberman *et al.* 2005) and transcranic magnetic stimulation (Theoret *et al.*, 2005). Oberman *et al.* (2005) showed that autistic individuals, at difference with healthy subjects, did not show mu frequency suppression over the sensory-motor cortex during action observation. Using transcranic

magnetic stimulation (TMS), Theoret *et al.* (2005) found no induced hand muscle facilitation during hand action observation in subjects affected by autism.

These abnormalities may account for the behavioural effects shown in the present study. If the action observation system participates in coding motor intentions behind the observer's gaze direction (Pierno *et al.*, 2006*c*), then impairments in connectivity and/or functioning of this network may explain why autistic children are immune from transfer of interference.

In this view theorizing about other minds might not be the basic deficit in autism: if children with autism appear blind to the mental significance of gaze, this might be because they are immune from motor contagion by gaze, i.e. they lack a starting point in mentalizing. Indeed, this may explain why in social situations salience of eyes is reduced for individuals with autism (Klin *et al.*, 2002*a*). An adequate interpretation of a social situation often requires to process social cues rapidly. Measuring visual fixations patterns during viewing naturalistic social situations, Klin *et al.* (2002*a*) found that whereas normal individuals focused primarily on the eye region, individuals with autism preferentially fixated the mouth and the lower portion of the face. It has been proposed that this pattern of fixation reflects a strategy as to compensate for the difficulty of reading mentalistic information from eye gaze. In other words, because the eyes are not meaningful to them, children with autism concentrate their effort on mouth, which is where the speech comes from (Klin *et al.*, 2002*a*). This proposal is consistent with the evidence that motor contagion from eye gaze does not occur in autistic children. If salience of eyes is reduced in autism, this might be because children with autism are immune from motor contagion from eye gaze.

More generally, absence of motor contagion from eye gaze could lead to 'impaired formation and coordination of specific self–other representations' which lay at the root of the cascade of autistic social disturbances (Rogers and Pennington, 1991). Whereas typically developing infants automatically translate between what they see and what they do, children with autism appear unable to establish a motor equivalence between the self and other representations (see also Gallese, 2006). This failure, which first manifest in impaired imitative abilities, may prevent/interfere with the further development of reciprocal social abilities including joint attention, social and communicative interactions, as well as empathy and theory of mind. The present findings complement and extend the concept of a linkage between imitative phenomena and theory of mind deficits in autism (e.g. Rogers and Pennington, 1991; Meltzoff and Gopnik, 1993; Williams *et al.*, 2001; Iacoboni and Dapretto, 2006; Oberman and Ramachandran, 2007), suggesting that motor contagion from eye gaze may be crucial for translating from the observed to the executed actions. In this respect, absence of motor contagion from eye gaze may contribute and exacerbate deficits in

imitation, precluding an automatic contagion from the observed action.

In conclusion, our findings revealed that whereas gaze processing is necessary and sufficient as to elicit motor contagion in typically developing children, autistic children are immune from contagious processes both from action and eye observation. Since contagious processes may be fundamental as to read intention in others' actions and gaze, these findings may help us to understand the impairments exhibited by autistic children in social interaction and mentalizing ability.

Acknowledgements

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