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FAR FROM ACTION-BLIND: REPRESENTATION OF OTHERS' ACTIONS IN INDIVIDUALS WITH AUTISM

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It has been suggested that theory of mind may rely on several precursors including gaze processing, joint attention, the ability to distinguish between actions of oneself and others, and the ability to represent goal-directed actions. Some of these processes have been shown to be impaired in individuals with autism, who experience difficulties in theory of mind. However, little is known about action representation in autism. Using two variants of a spatial compatibility reaction time (RT) task, we addressed the question of whether high-functioning individuals with autism have difficulties in controlling their own actions and in representing those of others. Participants with autism showed automatic response activation and had no difficulties with response inhibition. When two action alternatives were distributed among pairs of participants, participants with autism represented a co-actor's task, showing the same pattern of results as the matched control group. We discuss the possibility that in high-functioning individuals with autism, the system matching observed actions onto representations of one's own actions is intact, whereas difficulties in higher-level processing of social information persist.

Recently, a number of authors have suggested that the ability to explain and predict other people's behaviour by attributing mental states to them—also known as having a "theory of mind" (ToM)—may be built on more basic processes of social cognition. Among these functions are the ability to distinguish between animate and inanimate entities (Frith & Frith, 1999), the ability to share attention (Baron-Cohen, 1994; Baron-Cohen & Cross, 1992; Leekam et al., 1997), the ability to distinguish between actions of oneself and others (Frith, 1996; Russel & Jarrold, 1999), and the ability to represent goal-directed actions (Blakemore & Decety, 2001; Frith & Frith, 1999; Frith, 2002; Leslie, 1994).

A large number of studies has shown that individuals with autism have impairments in ToM (for a review, see Baron-Cohen, 2000; Sodian, in press).

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These studies have mainly addressed the ability to understand that other people can have beliefs and desires different from one's own. Far fewer studies have addressed the question of whether autistic individuals also show deficits in the abilities thought to precede and underlie ToM. In particular, little is known about action representation in individuals with autism (cf. Moore, Hobson, & Lee, 1997).

In the present study, we addressed the question of whether autistic individuals have difficulties in controlling their own actions and in representing others' actions. With regard to action control, we investigated their ability to inhibit prepotent responses in a two-choice RT task, and their ability to inhibit responses in a go–nogo task. By distributing two action alternatives among pairs of participants, we investigated whether individuals with autism represent a co-actor's task and integrate it in their own action planning. To provide a theoretical context for our study, we first discuss recent findings that provide evidence for a link between ToM and more basic underlying processes of social cognition. We then derive predictions for action representation in autistic individuals, drawing on the three major theories developed to explain the cognitive characteristics observed in the autism spectrum disorders.

PRECURORS TO ToM

According to Tomasello, Kruger, and Ratner (1993), three levels of social understanding can be discerned. The first level is assumed to support the perception of the behaviour of animate beings and to allow one to predict the consequences of the observed behaviour. The second level entails the understanding that others' behaviour is goal-directed. Thus, on this level, other individuals are conceived of as intentional agents whose behaviour and attention are purposive. The third level of understanding corresponds to ToM, where other individuals are conceived of as agents whose thoughts and beliefs may differ from those directly inferred from their perceived behaviour. Neurophysiological and brain imaging results provide evidence that specific brain systems underlie the abilities at each of these levels, and may also support different abilities across levels. However, one must be cautious in drawing conclusions regarding the relationship between ToM and its putative precursors, as the data only provide indirect evidence for such a link.

Several studies have addressed the ability to distinguish between animate and inanimate entities (Blakemore & Decety, 2001; Frith, 1996). In order to be able to predict the behaviour of other individuals, it is crucial to identify the motion of animate beings from other forms of motion in the environment. Specific neural structures underlying this ability have been found in monkeys and humans. Single-cell studies have revealed cell populations in the monkey superior temporal polysensory area (STP) that respond selectively to biological motion (Oram & Perrett, 1994), and functional magnetic resonance imaging (fMRI) studies in humans have shown that a specific area, located in the superior temporal sulcus (STS), is specialised for processing biological motion (Grèzes & Decety, 2001; Grossmann et al., 2000).

A skill pertaining to the second level that has been proposed as a precursor to mentalising is the ability to infer others' intentions through gaze following and shared attention (Baron-Cohen, 1994; 1995; Baron-Cohen & Cross, 1992; Leekam et al., 1997). Evidence for this claim has recently been provided by neurophysiological studies. Using single cell recordings in macaque monkeys, Jellema et al. (2000) discovered a population of cells in the anterior part of the superior temporal sulcus (STSa), which responds selectively to the sight of reaching movements, but only when the agent performing the action is also seen to be attending to the target position of the reaching movement. Thus, these cells are at the same time sensitive to action and attention. The authors concluded that the combined analysis of direction of attention and body movements in STSa supports the detection of intentional actions. In line with this claim, fMRI studies in humans have shown that eye gaze processing and ToM tasks engage a similar region of the posterior STS (Calder et al., 2002; Frith & Frith, 1999; Gallagher et al., 2000). A second brain region associated with ToM, the medial prefrontal cortex, has recently also been shown to be activated during gaze processing (Calder et al., 2002).

A further mechanism assumed to underlie the understanding of others' intentions is the matching of an observed action onto a representation of one's own action. This mechanism relies on a close link between perception and action systems. According to the common coding theory (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997), actions are coded in terms of the perceivable effects they should generate. When an effect is intended, the movement that produces this effect as perceptual input is automatically activated, because actions and their effects are stored in a common representational domain. A further consequence of this match between perception and action is that observing actions or action effects produced by another individual may also activate a representation of one's own actions. Evidence from neurophysiological studies in monkeys suggests that common coding may occur at the level of single neurons. Mirror neurons in area F5 of the premotor cortex respond both when a monkey performs a certain action and when it observes another individual perform the same action (Gallese et al., 1996; Rizzolatti, Fogassi, & Gallese, 2001). Thus mirror neurons seem to form a system matching the observation and execution of goal-related actions.

Studies using Transcranic Magnetic Stimulation (TMS; Fadiga et al., 1995; Strafella & Paus, 2000), Positron Emission Tomography (PET; Decety et al., 1994; Grafton et al., 1996) and fMRI (Buccino et al., 2001) suggest that a mirror system also exists in humans, and that there is, to some degree, a functional equivalence between simulating, observing, and performing an action. Several areas, such as the supplementary motor area, the dorsal premotor cortex, the supramarginal gyrus, and the superior parietal lobe are activated when an action is imagined or carried out as well as when the same action is observed in others (Grèzes & Decety, 2001). It has been suggested that the function of this matching system may be to understand others' intentions through action simulation (Blakemore & Decety, 2001; Rizzolatti et al., 2001). Action simulation would allow one to infer what one's own intentions would be if one produced the observed action in the same context. This function could be a precursor to a more general mentalising ability (Gallese & Goldman, 1998).

Deficits in precursors to ToM in autism

A number of studies suggest that individuals with autism have difficulties with abilities assumed to underlie ToM. These include the ability to share attention with another person (Carpenter, Pennington, & Rogers, 2002; Leekam & Moore, 2001; Mundy & Stella, 2000), the ability to use and understand protodeclarative pointing (Baron-Cohen, 1989a), and the ability to infer mental states from gaze direction (Baron-Cohen, 1995; Baron-Cohen et al., 1995; Baron-Cohen & Cross, 1992; Leekam et al., 1997). Although action representation is also regarded as a precursor to ToM, little is known about deficits in action representation in individuals with autism, with the exception of imitation.

Clinical reports of autistic individuals' difficulties in imitation date back many years (e.g., Bosch, 1970; Kanner, 1943; Wing, 1969). Several studies reviewed by Meltzoff and Gopnik (1993) have shown that children with autism perform less well than controls on motor imitation of both pure body movements and actions on objects, and have particular problems imitating simple body movements (Curcio, 1978; Dawson & Adams, 1984; DeMyer et al., 1972; Jones & Prior, 1985; Sigman & Ungerer, 1984). A difficulty in copying body movements, gestures, single, and sequential actions has also been reported in older and high-functioning children with autism (Ohta, 1987; Rogers, 1998).

It has been suggested that the impairment in imitation may be due to deficits in the coordination of representations of self and other (Hobson & Lee, 1999; Rogers & Pennington, 1991). According to Williams et al. (2001), a delay or incomplete development of the mirror neuron system could lead to impaired formation and integration of self–other representations. They proposed that deficits in ToM, but also some of the other deficits observed in autism spectrum disorders, may be the result of a poorly functioning system of mirror neurons.

COGNITIVE THEORIES OF AUTISM

The three major theories developed to explain the cognitive deficits observed in individuals with autism (Sodian, in press) allow one, to some degree, to derive predictions about action representation. These theories conceptualise the cognitive deficits as a difficulty in ToM, an impairment in executive functioning, and an imbalance in the integration of information. They address different characteristics of cognitive processing and are not mutually exclusive. While the ToM approach focuses on the social difficulties observed in autism, the executive function theory and the theory of weak central coherence focus on the nonsocial deficits. In addition, the theory of weak central coherence aims to explain findings of superior performance.

The ToM deficit approach

Theories pertaining to this approach are based on the assumption that children with autism do not develop the ability to attribute mental states to themselves and to others as a way of explaining and predicting behaviour in the way that healthy children do. The performance of autistic children on false-belief tasks, which test the understanding that other people can have different beliefs from one's own in the same situation, supports this notion (for a review, see Baron-Cohen, 2000). It has repeatedly been shown that children with autism have difficulties in shifting their perspective to understand what another person thinks, instead of simply reporting what they themselves know (Baron-Cohen, Leslie, & Frith, 1985, 1986; Leekam & Perner, 1991; Perner et al., 1989).

Although some autistic children pass first-order tests, which require inferring another person's mental state, they do so at a much later age than healthy controls (Happé, 1995), and they often fail at second-order false belief tasks (Baron-Cohen, 1989b). Second-order tests involve considering embedded mental states; i.e., to solve these tasks, one needs to infer one person's beliefs about another person's beliefs. Some individuals with autism or Asperger Syndrome who are high functioning in terms of IQ and language (i.e., score at least average on corresponding tests) pass second-order tests (Bowler, 1992; Happé, 1993; Ozonoff, Pennington, & Rogers, 1991). However, they often show difficulties in advanced ToM tests, where one needs to infer complex mental states such as bluff and double-bluff in story characters (Happé, 1994), or where one needs to decode complex mental states from the expression in the eye region of the face (Baron-Cohen et al., 1997; Baron-Cohen, Wheelwright, & Joliffe, 1997).

Two different versions of the ToM deficit approach can be distinguished (cf. Russell & Hill, 2001). According to one view, the difficulty in understanding mental states is restricted to representational mental states such as beliefs (Leslie, 1987). According to the other view, all forms of mentalising are impaired, whether or not they take the form of beliefs (Baron-Cohen, 1989b, 1995; Baron-Cohen et al., 1997). What predictions about action representation in individuals with autism can be made on the basis of these views? Assuming that a more general deficit in mind-reading is present, one may predict that individuals with autism should also have difficulties in representing others' actions, and in integrating representations of their own and others' actions. This prediction is also supported by findings of deficits in more basic abilities, such as shared attention, gaze following, and, in particular, imitation. The representational view does not exclude the presence of other, non-ToM deficits. However, it is worth noting that the core assumption of this view does not imply that individuals with autism should show any impairments in controlling their own actions and in representing others' actions.

The executive deficit theory

Besides mentalising difficulties, individuals with autism also experience executive difficulties, that is, difficulties with action planning, action initiation, and action control. Whether and how the two difficulties are related is still controversial (Sodian, in press). Executive deficits have been found in individuals with autism of different ages and different IQ levels (e.g., Hughes & Russell, 1993; Hughes, Russell, & Robbins, 1994; for a review, see Ozonoff, 1997), among them also high-functioning adolescents and adults (Ozonoff et al., 1991; Rumsey, 1985). Several studies have tried to identify the specific executive function components that are impaired. In particular, two possibilities have been suggested: First, it could be that individuals with autism have an inhibitory deficit. This could apply to the inhibition of actions in general, or specifically to the inhibition of actions that have been pre-activated by the context and are thus prepotent (Hughes & Russell, 1993; Russell et al., 1991). Second, there could be difficulties with cognitive flexibility (Courchesne et al., 1994), e.g., the ability to switch between different tasks may be impaired.

Difficulties with the inhibition of prepotent responses have been reported (Hughes & Russell, 1993; Russell et al., 1991). For instance, in the "box" task (Hughes & Russell, 1993), children with autism showed difficulties inhibiting a direct reach for a desired object and throwing a switch before reaching instead. Furthermore, the empirical evidence suggests that individuals with autism have problems with cognitive flexibility (Courchesne et al., 1994). The evidence for impairments in action inhibition in response to neutral stimuli is mixed (Ozonoff & Strayer, 1997; Ozonoff, 2000). In a study by Ozonoff et al. (1994), the performance of autistic individuals in a go–nogo task was unimpaired. This task requires that one carries out a response to a neutral cue, the go stimulus (e.g., a circle), while simultaneously inhibiting responses to another neutral cue, the nogo stimulus (e.g., a square). In contrast, autistic individuals were clearly impaired in their performance when the mapping between the stimuli and the corresponding responses was frequently changed, placing demands on their ability for set-shifting.

Pacherie (1997) suggested that the executive difficulties of individuals with autism may originate from a specific impairment of their motor representations. According to her account, conscious access to motor representations gives individuals a basic form of awareness of the relationship between their representations and their actions, and of their status as agents and as the owners of representations. In particular, it allows one to experience a continuity between one's prior intentions and one's intentions-in-action (Searle, 1983). Pacherie assumes that individuals with autism have an impaired capacity for motor imagery and, hence, have difficulties in forming conscious motor representations. As a consequence, they have difficulties in simulating actions and in forming action plans, and they fail to experience themselves as the agents responsible for the continuity between their intentions and their actions. Pacherie points out that an impairment in the formation of motor representations could also lead to difficulties in mentalising. In order to attribute intentions to others, one must be able to construct motor representations when observing an action performed by someone else and match the observed action onto a representation of one's own (cf. Blakemore & Decety, 2001).

In a similar vein, Russell and Jarrold (1999) argued that individuals with autism fail to make an efference copy of their actions in a visual code. This may lead to deficits in self-monitoring, manifesting themselves as a difficulty with correcting errors and as a tendency to misdescribe intended actions. In a study on memory for actions, the authors showed that children with autism were impaired relative to normally developing children and children with mental handicap at remembering which actions had been performed by themselves and which had been performed by another person (but see Russell & Hill, 2001, for a study showing intact reporting of own intentions).

Taken together, the executive deficit account predicts deficits in action representation in individuals with autism that should affect the control of their own actions as well as the formation of representations of others' actions, and the integration of representations of self and other. In contrast, the deficits observed in precursors to ToM suggest a specific impairment of action representation in the social domain. Individuals with autism should have difficulties representing others' actions, but should be unimpaired in controlling their own actions.

The weak central coherence theory

Whereas the ToM approach and the executive deficit theory focus on the cognitive impairments observed in autistic individuals—the former addressing primarily social, the latter primarily nonsocial deficits—the theory of weak central coherence has been developed to explain findings of superior performance (e.g., Rimland & Hill, 1984) as well as nonsocial impairments. Assuming that the deficits and the assets in autism stem from a single cognitive characteristic, Frith (1989) proposed that individuals with autism are characterised by a specific imbalance in the integration of information at different levels. Central coherence, defined as the tendency to integrate diverse information to construct higher-level meaning in context, is assumed to be a characteristic of human information processing. According to Frith, this feature of information processing is disturbed in autism, leading to enhanced performance on tasks where attention to local information and piecemeal processing is advantageous, and to impaired performance on tasks requiring the recognition of global meaning or the integration of stimuli in context. Empirical evidence for this claim has been obtained at different levels of processing, ranging from low-level perceptual processes to higher levels involving the semantic system (for a review, see Happé, 2000).

A number of different studies suggests that weak central coherence is not related to ToM and may be present in all individuals with autism regardless of their ToM ability (Frith & Happé, 1994; Happé, 1996). According to Happé's view, there may, however, be a link between central coherence and general social understanding. She points out that in order to understand others' thoughts and feelings, one needs to take into account the context of a situation and integrate diverse information. It is likely that individuals with weak central coherence and detail-focused processing are at a disadvantage when it comes to integrating information necessary for social inference.

Following this notion, one may speculate that individuals with autism are also more likely than healthy controls to ignore others' actions in social context (cf. Baron-Cohen et al., 1999). This should especially be the case when others' actions have no direct bearing on their own, e.g., when there is no need for action coordination. Thus a deficit in action representation could be the consequence of a more general deficit in taking the social context of a situation, including other agents, into account. So far, weak central coherence has mainly been investigated with respect to nonsocial information processing. It remains to be examined whether this cognitive style also affects information processing within social context.

THE CURRENT STUDY

The aim of the present study was to investigate whether individuals with autism show impairments in action control and in representing others' actions. To exclude the possibility that any observed differences between autistic individuals and healthy control participants are attributable to a more general cognitive impairment, we decided to focus on high-functioning adolescents and adults with autism, who are normally intelligent and quite proficient in ToM tasks.

Action control

With regard to action control, we focused on two questions. First, do individuals with autism show difficulties inhibiting pre-activated and thus prepotent responses? Second, is the inhibition of responses to neutral cues impaired? To address the first question we devised a variant of a well-known spatial compatibility RT task, the Simon task (Craft & Simon, 1970; Simon, 1990). In a typical Simon task, one carries out a spatial two-choice response to a relevant stimulus feature (e.g., colour) that is presented along with an irrelevant spatial stimulus feature (e.g., location). In our version of the task, the stimuli were pictures of a hand pointing left or right. A red or green ring was attached

(a) Joint setting

(b) Individual setting

Figure 1. *Setting (a) in the joint go–nogo task, and (b) in the individual go–nogo task.*

to the index finger of the hand. The ring colour was the relevant stimulus feature, and the pointing direction of the index finger was the irrelevant spatial stimulus feature. The standard finding in a Simon task is that responses are faster when there is an overlap between the irrelevant stimulus dimension and the response, and slower when the two conflict. For example, in our case, a person could be instructed to respond with a left key when the ring is red and to respond with a right key when the ring is green. On trials where the ring is red and the finger points left, and on trials where the ring is green and the finger points right, the irrelevant spatial dimension corresponds to the response to be given. Responses should be faster on these compatible trials compared to incompatible trials where the irrelevant spatial dimension and the response to be given do not correspond, i.e., where the ring is red and the finger points right, and where the ring is green and the finger points left.

According to Kornblum et al.'s dimensional overlap model (1990), this compatibility effect emerges because the irrelevant spatial dimension of the stimulus overlaps with the spatial dimension of the responses. Due to this overlap, the response corresponding to the spatial information provided by the stimulus will be automatically activated. For instance, when the finger points left, the left response is activated, and when it points right, the right response is activated. Responses are speeded when the response is the same as the one indicated by the relevant stimulus dimension, and slowed when the two conflict (see also Hommel & Prinz, 1997).

Predictions for the two-choice task: Control group. We expected a standard spatial compatibility effect for participants in the control group. Thus responses should be faster on compatible trials where the irrelevant spatial dimension and the response correspond, and slower on incompatible trials, where they conflict.

Predictions for the two-choice task: Autistic group. Different predictions can be derived from each of the three main theoretical approaches outlined above. Assuming that the cognitive deficits observed in autism are mainly due to a difficulty in ToM, there should be no difference in performance between the control group and the autistic group, because the task does not involve mentalising. Thus, like healthy controls, individuals with autism should show a compatibility effect. The executive deficit theory suggests that individuals with autism may have difficulties inhibiting prepotent responses. A response that has been preactivated by the irrelevant spatial dimension can be regarded as a prepotent response. Thus, on incompatible trials, where the pre-activated response must be inhibited, response conflict should be increased. This should result in a larger compatibility effect and/or a higher error rate on incompatible trials. Finally, from the findings of weak central coherence in visual processing (cf. Happé, 2000) one may infer that individuals with autism will be particularly good at focusing on the relevant stimulus feature and at ignoring the irrelevant dimension. Thus, they should be able to process the ring colour while ignoring the pointing stimulus. If the irrelevant spatial dimension is not consistently processed, there is less automatic response activation. Therefore weak central coherence predicts that individuals with autism should show a smaller compatibility effect than controls.

Our two-choice task can easily be transformed to a go–nogo task by assigning only one response alternative to a participant, so that he or she responds only to one color and not to the other (cf. Figure 1b). This allows one to further investigate whether autistic individuals have problems inhibiting responses to certain stimuli while responding to others.

Predictions for the go–nogo task: Control group. Usually, spatial compatibility effects are only observed in two-choice and not in go–nogo RT tasks (for an exception, see Hommel, 1996). Thus, no compatibility effect was expected. Responses should be equally fast no matter where the finger points, because there is no overlap between the spatial stimulus feature and the response, and hence, automatic response activation cannot occur.

Predictions for the go–nogo task: Autistic group. Assuming that a deficit in ToM is the central deficit of individuals with autism, no difficulties for this task are expected, because mentalising is not involved. The performance of participants with autism should not differ from the control group. However, results from studies on executive functioning suggest that individuals with autism might have difficulties inhibiting the response to certain stimuli while responding to others (Ozonoff, 1997). If weak central coherence affects visual processing of the stimuli in the way described above, no compatibility effect should occur.

Representation of others' actions

To investigate whether and how others' actions are represented we distributed the two-choice RT task among pairs of participants in two different ways (Experiment 1 and 2). In Experiment 1, each participant took care of one action alternative; each participant performed the go–nogo task in response to colour alongside another participant responding to the complementary colour (joint go–nogo condition; cf. Figure 1a). Performance in the group setting was compared to performance on exactly the same task in a setting in which the other participant was absent (individual go–nogo condition, as described above; cf. Figure 1b).

Predictions for the control group. For the joint and individual go–nogo condition, we expected to replicate findings from a previous study using the same paradigm (Sebanz, Knoblich, & Prinz, 2003a). Hence, we predicted that there would be a compatibility effect in the joint go–nogo condition, as opposed to the individual go–nogo condition. In the joint go–nogo condition, responses should be faster on trials where the finger points at the person to respond (compatible trials) and slower on trials where it points at the person not to respond (incompatible trials). Given that the task in the individual and the joint go–nogo condition is exactly the same, such a pattern of results can be interpreted as evidence that in the group, each participant represents not only his or her own task, but also the task at the other's disposal.

Predictions for the autistic group. To derive predictions for the autistic group, one must first consider what sort of demands on cognitive processing the task makes. Clearly, the optimal performance strategy for this task in the group condition is to ignore the other person and perform the task as if one were on one's own. However, previous results suggest that when two action alternatives are distributed among two participants, each participant represents the other's task (Sebanz et al., 2003a, 2003b). To form a representation of the other's task, only a very basic form of ToM is needed.

Given that our participants were high-functioning and able to solve first- and second-order ToM tasks, the representational view of a ToM deficit (Leslie, 1987) suggests they should behave like healthy controls, unless other nonmentalising deficits are present. Hence, a compatibility effect in the joint go-nogo condition should be observed. However, findings of action representation deficits in imitation (Meltzoff & Gopnik, 1993) and deficits in action monitoring (Russell & Jarrold, 1999) suggest that individuals with autism might not represent the other's actions, and hence, show no compatibility effect. Such a finding would be compatible with the assumption of a general mind-reading deficit (Baron-Cohen, 1995). This prediction also follows from the notion of an impaired mirror system (Williams et al., 2001), and the notion of an impairment in the formation of motor representations as suggested by Pacherie (1997). The theory of weak central coherence predicts no joint compatibility effect for two reasons: First, as for the two-choice condition and the individual go–nogo condition, it predicts that the irrelevant pointing direction is not processed. Hence, there should be no compatibility effect. Second, one could assume that weak central coherence also characterises the way the social context is processed (cf. Baron-Cohen et al., 1999). In this case, the other person should be ignored, and the task should be performed as if one were alone.

EXPERIMENT 1

Method

Participants

Thirteen high-functioning adults with autism or Asperger Syndrome (AS) and 13 healthy controls took part in Experiment 1. The participants with autism were recruited from MAut, a local care centre where they took part in a 2 year training programme aimed at vocational and social integration. The control group was recruited through advertisements in local newspapers. Eight of the autistic subjects had received a clinical diagnosis of Asperger Syndrome (AS), three of autism, and two of atypical autism.[1] None of the participants had a history of psychiatric disorder, neurological disorder, or a head injury. The control group was free of any family history of autism or AS. All participants had normal or corrected-to-normal vision. They received payment for their participation.

All participants were required to be of at least average intelligence (i.e., scoring >85) on the HAWIE-R (the German version of the WAIS-R; Tewes, 1994) on the full scale, performance, and verbal IQ. All except one participant from the autistic group and all participants from the control group passed first- and second-order ToM tasks. Each participant was given two first-order ToM tasks, two second-order ToM tasks, and two advanced stories (Happé, 1994). The first-order ToM tasks were the Smarties task (Perner et al., 1989) and a modified version of the Sally-Anne task (Wimmer & Perner, 1983). The second-order ToM tasks were Baron-Cohen's ice-cream van test (1989b), and the grandparents story (Hughes et al., 2000). The advanced stories comprised one double- bluff story and one persuasion story (Happé, 1994). Participants in the control group solved on average 5.7 of the 6 tests ($SD = 0.5$), whereas participants in the autistic group solved on average 4.7 of the 6 tests ($SD = 1.5$). Although all except one participant from the autistic group passed at least one of two tests in each category (first order, second order, and advanced), a two-tailed t-test showed that performance of the autistic group was clearly worse than performance of the control group, $t(12) = 2.45, p < .05$.

The control participants were chosen to match the clinical group as closely as possible with respect

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[1] There has been a lot of controversy about whether there is as single condition of autism that varies in severity, or whether there are different types of autism (cf. Frith, 1989; Miller & Ozonoff, 1997; Happé, 1994). The most conspicuous difference between autism and AS is that in the former, there is often a delay in language development, whereas in the latter, language skills are unimpaired. Since we did not predict any differences in performance between individuals with autism and AS for our study, we included individuals with either diagnosis. By using the term "individuals with autism" we refer to both groups.

Table 1. *Experiment 1: Participant characteristics*

Group	*CA*	*VIQ*	*PIQ*	*FSIQ*
Control[a]				
Mean	19.85	113.69	118.46	117.85
SD	2.97	8.46	10.97	8.67
Range	(16–28)	(100–131)	(98–138)	(104–132)
Autism[a]				
Mean	20.92	105.38	109.46	109.00
SD	4.19	11.62	15.02	10.07
Range	(16–29)	(92–124)	(85–130)	(98–126)

[a] Both groups $n = 13$; 3 female.

to age, IQ, level of education, sex, and handedness. Table 1 gives the participant details of chronological age (CA), verbal IQ (VIQ), performance IQ (PIQ), and full scale IQ (FSIQ). Two-tailed t-tests showed no significant difference in chronological age, verbal IQ, and performance IQ between the two groups (all $p > .05$). However, there was a significant difference between the two groups with respect to full scale IQ, which was somewhat higher in the control group, $t(12) = 2.46$, $p < .05$. The IQ test and the ToM tests were carried out in a seperate session before the experiment. For the participants from the clinical group, this test session was performed at the integration centre.

Materials and procedure

Participants observed digital photographs of a right hand pointing to the left or to the right. On the index finger of the hand there was a ring coloured red or green (see Figure 2). The stimuli were presented centrally on a computer monitor, and the ring always appeared at the same location. Picture size was about 15 × 13 visual degree horizontally and vertically. The order of events in each trial was as follows: a fixation cross appeared for 100 ms, followed by a blank screen for 100 ms. Then a picture of the hand appeared. Three different stimulus onset asynchronies were used (cf. Figure 2b): The irrelevant pointing direction was either presented at the same time as the relevant ring colour (SOA 0), or it was presented some time in advance (100 ms or 300 ms). In the latter case, the ring on the index finger of the hand was initially grey and then turned red or green after 100 ms (SOA 100) or 300 ms (SOA 300), respectively. The SOA variation was introduced to prevent participants from developing response strategies and stable patterns of responding. The picture with the relevant colour cue remained on the screen for 500 ms. After a response time interval of 1000 ms, the next trial was initiated.

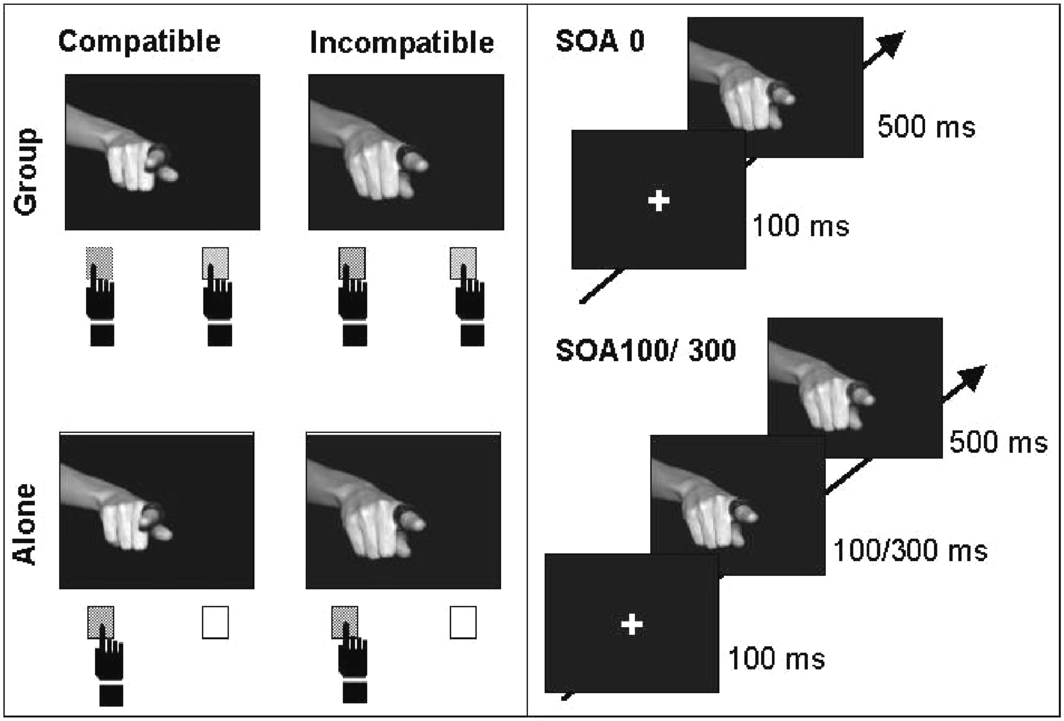
There were three different parts of the experiment. All participants performed the standard two-choice RT task, and the go–nogo task in an individual and a joint condition. In the two-choice task, they were instructed to respond to one ring colour with a left and to the other with a right button press. In the joint go–nogo condition, the original task was distributed among two individuals, so that each participant responded to only one of the two colours (see Figure 1a). Thus for each person, the task was a go–nogo task. In the individual go–nogo condition, the identical go–nogo task was performed alone (see Figure 1b). For the two-choice task, participants sat centrally in front of the screen. In the joint go–nogo condition, they sat side-by-side with a distance of about 40 cm between them. In the individual go–nogo condition, an empty chair remained beside each participant. In each of the three parts of the experiment, participants completed four blocks of 126 trials presented in random order. The order of conditions was counterbalanced across pairs of participants.

Stimulus presentation and data collection were controlled by an Apple Power PC. The pictures were presented on an Apple 21" monitor (resolution 1024 × 768 pixels). Button presses were recorded with a PsyScope button box (Cohen et al., 1993).

Results

Two-choice task

The error rate in the control group was 2.7%, and in the autistic group 1.7%. This difference was marginally significant, $t(12) = 2.06$, $p = .06$. In both groups, there was a tendency towards more errors on incompatible trials ($p < .10$). Error trials and trials on which RTs exceeded 800 ms were excluded



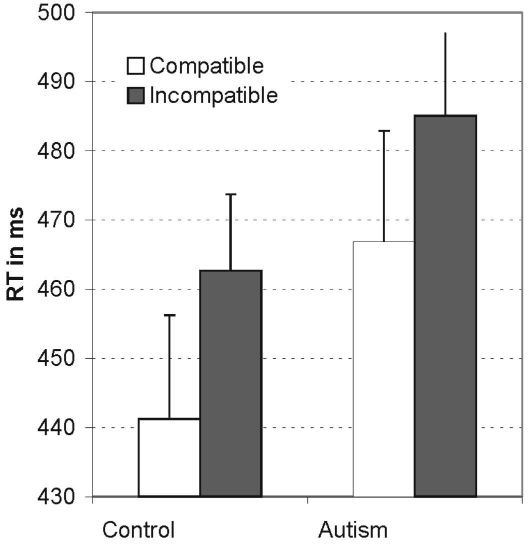
(a) Individual and joint go–nogo condition (b) Trial sequence

Figure 2. *(a) Graphic depiction of the task from the viewpoint of a participant sitting left and responding to red. Compatible trials are shown on the left, incompatible trials on the right. The upper panel shows the group setting, the lower panel the individual setting. (b) Sequence of events on each trial for SOA 0 (upper half) and SOA 100 and 300 (lower half).*

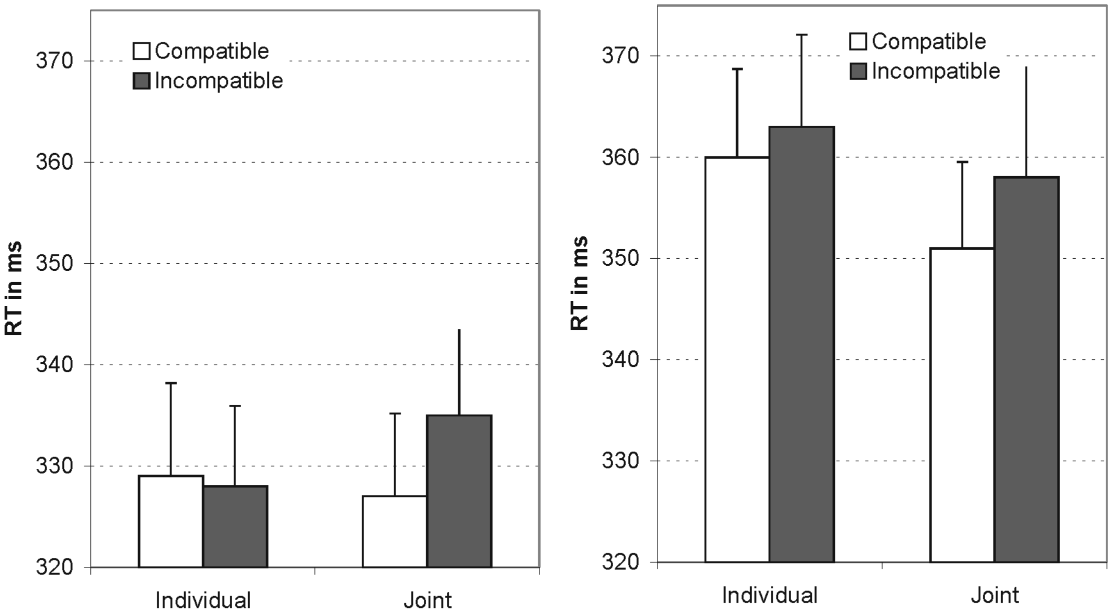
from the statistical analyses. These were approximately 5% of all trials in both groups. Figure 3a shows the results for the two-choice task. In both groups, mean RTs were faster on compatible than on incompatible trials. To analyse the observed RT differences, a 2×2 analysis of variance (ANOVA) with the between factor group (autistic vs. control) and the within factor compatibility (compatible and incompatible) was conducted. We do not report any SOA effects, because SOA did not interact with group. There was a significant main effect of compatibility, $F(1, 24) = 31.21$, $p < .001$. In both groups, RTs were faster on compatible than on incompatible trials. The general RT level in the two groups did not differ, $F(1, 24) = 1.66$, $p = .21$. The two-way interaction was not significant ($p > .05$).

Go–nogo task

The error rate for the control group was 1.2% in the joint go–nogo condition, and 2.8% in the individual go–nogo condition. For the autistic group, it was 1.8% in both conditions. There was no significant difference in error rate between the two groups, and between compatible and incompatible trials (all $p > .05$). Error trials and trials on which RTs exceeded 600 ms were excluded from the statistical analyses. Depending on the different groups and conditions, these were between 3.5% and 6.2%. Figures 3b and 3c show the results for the go–nogo conditions. In both groups, a compatibility effect was observed only in the joint go–nogo condition.



(a) Two -choice condition



(b) Go-nogo condition, control group

(c) Go-nogo condition, autism group

Figure 3. *Experiment 1: Mean RTs on compatible and incompatible trials in the two-choice condition (a), and in the individual and joint go–nogo condition for the control group (b), and the autism group (c).*

To analyse the observed RT differences, a $2 \times 2 \times 2$ ANOVA with the between factor group (control vs. autistic) and the within factors setting (individual and joint) and compatibility (compatible and incompatible) was conducted. SOA did not interact with group and is therefore not reported. There was a significant main effect of group, $F(1, 24) = 5.77$, $p < .05$. The general RT level in the control group was lower. There was no significant main effect of setting, $F(1, 24) = 0.26$, $p = .61$. The main effect of compatibility was significant, $F(1, 24) = 5.76$, $p < .05$. RTs were faster on compatible than on incompatible trials. Importantly, the interaction between setting and compatibility was significant, $F(1, 24) = 5.56$, $p < .05$. Post hoc tests (Newman-Keuls) confirmed that there was a significant difference between compatible and incompatible trials only in the joint setting ($p < .05$).

Finally, we analysed the RT differences in the autistic group seperately to determine whether the observed pattern of results, in particular the interaction between setting and compatibility, was present in this group. A within-subjects 2×2 ANOVA with the factors setting (individual and joint) and compatibility (compatible and incompatible) showed a significant main effect of compatibility, $F(1, 12) = 4.82$, $p < .05$, but the interaction between setting and compatibility did not reach significance, $F(1, 12) = 1.59$, $p = .23$. A Newman- Keuls post hoc test showed a significant difference between compatible and incompatible trials in the joint condition ($p < .01$), but not in the individual condition.

Discussion

The results for the two-choice RT task showed no difference between the autistic group and the control group. In both groups, a spatial compatibility effect was observed. This finding suggests that in both groups, the irrelevant spatial dimension was automatically processed and activated the corresponding response. Responses were faster when the irrelevant spatial dimension and the response indicated by the colour corresponded, and slower when the two conflicted. For the control group, this pattern of results had been expected. For the autistic group, these results had been predicted by the ToM deficit approach, suggesting that performance should not differ from the control group because mentalising is not involved. The prediction derived from weak central coherence theory, implying that autistic individuals would be able to focus only on the relevant colour stimulus and ignore the irrelevant pointing dimension, was not confirmed. Also, the prediction of deficits in the inhibition of prepotent responses derived from the executive deficit account was not confirmed. It must be noted, however, that previous findings of such deficits were obtained with more severely impaired autistic individuals, and with different tasks.

The results of the individual go–nogo condition provide further evidence that action control in the autistic group was intact. Participants with autism did not have specific problems inhibiting the response to certain stimuli and responding to others. This is in line with previous findings demonstrating that individuals with autism are unimpaired in their performance of go–nogo tasks (Ozonoff & Strayer, 1997; Ozonoff, 1997). This implies that the individual go–nogo condition can be regarded as a valid control condition for the joint go–nogo condition.

The results of the control group in the go–nogo conditions replicated previous findings. As expected, co-acting had an impact on the way a task was performed. Only in the group setting did the irrelevant spatial dimension affect RTs. Responses were faster on compatible trials, where the finger pointed at the person to respond, and slower on incompatible trials, where the finger pointed at the person not to respond. In previous experiments, we were able to show that this joint compatibility effect only appears when each participant is in charge of an action alternative. The effect does not appear in the mere presence of another person (Sebanz et al., 2003a). We interpret this finding as evidence that each participant represents not only his or her own action alternative, but also the action alternative at the other's disposal. When the finger points at oneself, this activates the representation of one's own action. When it points at the other agent, it activates the representation of the other's action alternative, creating response conflict. Thus, responses on compatible trials are facilitated, whereas responses on incompatible trials are impaired. In contrast, in the individual go–nogo condition, the other action alternative is not represented, and hence, there is no overlap between the irrelevant spatial dimension and the response. Thus no compatibility effect arises.

Surprisingly, the autistic group showed a similar pattern of results to the control group. A significant compatibility effect was present in the joint, but not in the individual, go–nogo condition. However, the interaction between setting and compatibility did not reach significance, so that the results must be interpreted with caution. At this point, it cannot be determined whether the co-actor was ignored or whether participants with autism represented the co-actor's task. On the one hand, a numerical difference between compatible and incompatible trials was also present in the individual go–nogo condition. It could be that this effect did not reach significance due to a problem of statistical power. This would imply that there was no difference between the two different settings and that the participants with autism ignored the co-actor. On the other hand, it could be that, again due to a problem of statistical power, the interaction between setting and compatibility did not reach significance, although the participants with autism represented the co-actor's task.

In the go–nogo conditions, the RT level was higher in the autistic group than in the control group. This difference between the two groups was also present in the two-choice task, but did not reach statistical significance, probably due to the large amount of variance in the autistic group. The slowing of participants with autism could be due to deficits in either central or more peripheral mechanisms of motor control. Another possibility is that it reflects more strategic processes. Behavioural observations during the testing session and the experimental session suggest that many of the participants with autism had a strong tendency to focus on accuracy rather than speed in their performance of different tasks. Thus the slowing in RTs could also reflect a speed–accuracy trade-off. As differences in the RT level do not affect our interpretation of the results, this issue is not discussed further.

EXPERIMENT 2

The results of Experiment 1 did not allow us to decide whether high-functioning individuals with autism ignore a co-actor, or integrate the other in their own action planning. In previous experiments, we showed that the joint compatibility effect increases in size in healthy adults when they perform the go–nogo task in response to colour alongside a co-actor responding to the pointing direction (Sebanz, Knoblich, & Prinz, 2003b). This result is best explained by the assumption that each co-actor represents the other's task. In Experiment 2, we thus asked the subjects who had participated in Experiment 1 to perform the joint go–nogo task alongside a confederate responding to the pointing direction. Again, the individual go–nogo condition served as a control.

Predictions for the control group. The predictions for the control group were the same as for Experiment 1, with the addition that we expected a larger compatibility effect in the joint go–nogo condition. In particular, RTs of the participant should be slower on trials where the finger points at the confederate (incompatible trials), because response conflict arises on these trials. The representation of the other's task and the corresponding action is activated, but the participant needs to respond him- or herself.

Predictions for the autistic group. For the autistic group, three different predictions can be made. First, it could be that the participants with autism represent the co-actor as an agent, but do not represent his or her specific task and the actions that are part of it. In this case, they should show a joint compatibility effect of similar size to that in Experiment 1. This prediction is supported by previous findings of deficits in action representation. Second, assuming that the participants with autism do represent the other's task, according to the executive deficit account, this may lead to difficulties in the coordination of the representation of their own and the other's actions. In contrast to Experiment 1, where on each trial only one of the two participants responded, the situation is more complex in Experiment 2, where in addition to trials where one participant responds, there are also trials on which both or neither respond. Therefore, one may expect an increase in the RT level and/or error rate due to the increased complexity of the task, or it could even be that participants are not able to perform the task adequately at all. Third, there may be no impairment in action representation. In this case, participants with autism should show a joint compatibility effect similar in size to the control group.

Method

Participants

Twelve adults with autism and 12 healthy controls took part in Experiment 2. All participants received payment for their participation. Twelve of the 13 participants with autism who had participated in Experiment 1 agreed to participate in Experiment 2. From the control group, eight of the participants from Experiment 1 were recruited again, and four additional participants were recruited through advertisements in local newspapers. They fulfilled the requirements described in Experiment 1. Again, the control group was matched as closely as possible in terms of age, IQ, level of education, sex, and handedness. Table 2 gives the participant details of chronological age (CA), verbal IQ (VIQ), performance IQ (PIQ), and full scale IQ (FSIQ).

Table 2. *Experiment 2: Participant characteristics*

Group	*CA*	*VIQ*	*PIQ*	*FSIQ*
Control[a]				
Mean	21.42	119.25	115.00	119.92
SD	3.37	12.76	10.09	10.31
Range	(16–29)	(100–137)	(98–130)	(104–137)
Autism[a]				
Mean	21.42	104.83	111.50	109.67
SD	4.30	11.96	13.68	10.21
Range	(17–29)	(92–124)	(85–130)	(95–126)

[a] Both groups $n = 12$; 3 female.

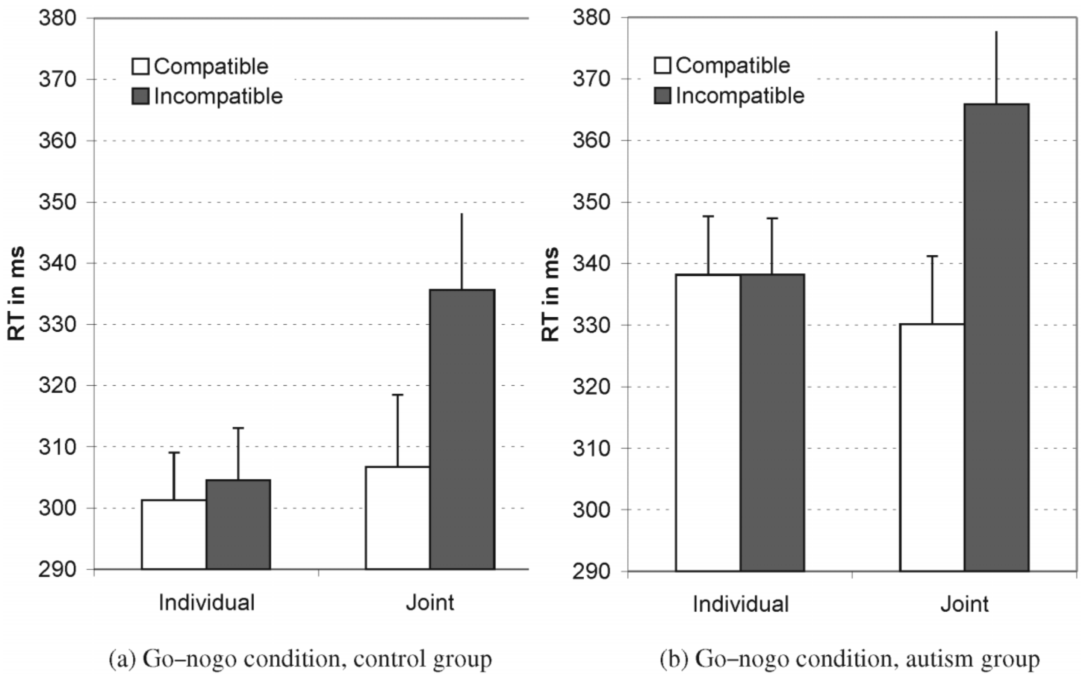
Materials and procedure

These were the same as in Experiment 1 with the following exceptions: Each participant carried out the go–nogo task alone (individual go–nogo condition) and alongside a confederate who carried out a go–nogo task in response to the pointing direction (joint go–nogo condition). The confederate responded when the finger pointed at her and did not respond when the finger pointed at the participant. Thus, on some trials, both individuals responded (25%), on some, none of them responded (25%), and on some, only the participant or only the confederate responded (50%, 25% each). The irrelevant pointing direction and the relevant colour cue always appeared at the same time (SOA 0). In both conditions (individual and joint), four blocks of 100 trials were presented. The order of conditions was balanced across participants. The order of events in each trial was as follows: A fixation cross appeared for 100 ms, followed by a blank screen for 100 ms. Then one of the four pictures appeared for 500 ms. After a response time interval of 1000 ms the next trial was initiated.

Results

The error rate for the control group was 1.3% in the joint go–nogo condition, and 2.6% in the individual go–nogo condition. For the autistic group, it was 1.7% in the joint and 1.2% in the individual condition. There was no significant difference in error rate between the two groups. In both groups, there were significantly more errors on incompatible trials in the joint go–nogo condition ($p < .001$). Error trials and trials on which RTs exceeded 600 ms were excluded from the statistical analyses. Depending on the different groups and conditions, these were between 3.0% and 3.3%. Figure 4 shows the results for the go–nogo conditions. In both groups, a large compatibility effect in the joint go–nogo condition was present.

To analyse the observed RT differences, a $2 \times 2 \times 2$ ANOVA with the between factor group (control vs. autistic) and the within factors setting (individual and joint) and compatibility (compatible and incompatible) was conducted. There was a



(a) Go–nogo condition, control group (b) Go–nogo condition, autism group

Figure 4. *Experiment 2: Mean RTs on compatible and incompatible trials in the individual and joint go–nogo condition for (a) the control group, and (b) the autism group.*

significant main effect for group, $F(1, 18) = 8.88$, $p < .01$. As in Experiment 1, the general RT level in the control group was lower. There was also a significant main effect for setting, $F(1, 18) = 7.93$, $p < .05$. RTs were slower in the joint go–nogo condition than in the individual go–nogo condition. The main effect for compatibility was significant, $F(1, 18) = 71.29$, $p < .001$; RTs were faster on compatible trials. Importantly, the interaction between setting and compatibility was again significant, $F(1, 18) = 109.41$, $p < .001$. In addition, the three-way interaction between group, setting, and compatibility was significant, $F(1, 18) = 4.46$, $p < .05$. Post hoc tests (Newman-Keuls) showed that in the control group, RTs on incompatible trials were significantly slower in the joint condition compared to the individual condition, whereas there was no difference between the two conditions with regard to RTs on compatible trials. However, in the autistic group, not only were RTs in the joint condition slower on incompatible trials, but RTs on compatible trials were faster compared to the individual condition (all $p < .05$). A two-tailed t-test comparing the size of the compatibility effect (difference between mean RTs on compatible and incompatible trials) in Experiments 1 and 2 within subjects showed that the compatibility effect was significantly larger in Experiment 2, $t(19) = 7.75$, $p < .001$.

Discussion

The results of Experiment 2 extend the findings of Experiment 1. A significant joint compatibility effect was observed in both groups. Numerically, it was about four times larger in size than in Experiment 1, suggesting that the nature of the co-actor's task had a specific impact on individual action planning. The pointing stimulus that was irrelevant for the participants' task, but relevant for the confederate, had a strong impact on the participants' actions. Participants responded faster when the finger pointed at themselves, requiring only their own response, and slower when it pointed at the confederate, requiring not only their own, but also the other's response. This provides evidence for the claim that participants represented the co-actor's task and integrated it in their action planning.

These findings are in accordance with the assumption that high-functioning individuals with autism have specific difficulties attributing representational states such as beliefs to others, but are unimpaired in more basic forms of mentalising, including action representation. The predictions derived from the executive deficit account were not confirmed, because difficulties in the coordination of the representation of their own and the other's actions were not observed.

Like in Experiment 1, the general RT level in the autistic group was higher than in the control group. As suggested before, this could reflect either central or more peripheral deficits in motor control, or a particular performance strategy. The RT level also differed between the two settings, RTs being slower in the group setting. This finding could reflect the increased difficulty of the task in the joint condition, where one represented not only one's own, but also the other's task.

The three-way interaction between group, setting, and compatibility suggests that in the group setting, individuals from the control group experienced interference on incompatible trials, whereas individuals from the autistic group also experienced facilitation on compatible trials. One possible post hoc explanation for this finding could be the following: On compatible trials, control subjects are already at ceiling, giving the response as fast as they can, and thus are not influenced by the spatial cue. Participants with autism may have a tendency to focus on accuracy and thus slow their responses to avoid errors. Given that their responses are not already as fast as possible, the cue can speed them up. A reason why this kind of facilitation did not appear in the joint go–nogo condition in Experiment 1 could be that the irrelevant dimension generally had less of an impact on actions.

Just as in Experiment 1, the amount of errors was so small that it is difficult to determine whether a group difference was present. Taking together the error results from Experiment 1 and 2, it seems that in the individual go–nogo condition, participants from the control group made more errors than participants from the autistic group, whereas there was no such difference in the joint go–nogo condition. Further investigation would be needed to find out whether this is a reliable pattern worth interpreting.

GENERAL DISCUSSION

Using a two-choice RT task, we demonstrated that high-functioning individuals with autism show the usual spatial compatibility effect, suggesting that they automatically process an irrelevant spatial cue that activates a spatial response. There was no evidence for a deficit in action control. Distributing the two-choice RT task among two persons allowed us to investigate whether a co-actor's task is represented. Our results suggest that when co-acting with another person, both individuals with autism and healthy controls represent the other's task.

These findings seem quite surprising given that impairments in action representation have been claimed by a number of authors, and have been shown in imitation and action monitoring. Furthermore, impairments in several other functions assumed to be pre-cursors to ToM have been reported, suggesting that there may be a link between mentalizing and more basic processes. The most surprising fact about our results is probably that individuals with autism represented another person's task despite the fact that their task did not require them to take the other person into account at all. We conclude from this finding that high-functioning individuals with autism may be mind-blind to some degree (Baron-Cohen, 1995), but they are far from action-blind.

It can be assumed that the joint compatibility effect observed in our experiments arises on a level at which one's own actions and others' actions are represented in a functionally equivalent way (cf. Sebanz et al., 2003a). As suggested by the common coding theory (Hommel et al., 2001; Prinz, 1997), observing actions performed by another person may activate the structures that are also involved in one's own control of these actions. Our findings suggest that in high-functioning individuals with autism, the system matching observed actions onto representations of one's own actions is unimpaired, contrary to Williams et al.'s (2001) proposal of an impairment of the mirror system.

This may lead one to speculate that high-functioning individuals with autism have a specific deficit in attributing representational states to others, whereas lower-level processing of social information is intact. Such a view has been propagated by Fodor (1992), Leslie and Thaiss (1992), and Scholl and Leslie (1999) who, among others, have proposed that the mentalising ability is based on a dedicated, domain-specific, and modular cognitive mechanism. We believe, however, that to interpret our findings in this way, additional evidence would be needed. First, the actions to be represented in our experiments were very simple. It is possible that our participants with autism would have had difficulties representing several different action alternatives, or complex action sequences. Hence, an impairment in the representation of more complex actions cannot be excluded. Second, it would be interesting to find out whether more severely impaired autistic individuals tested with the go–nogo condition would also show a joint compatibility effect, suggesting that they represent the other's task.[2] If this were the case, this would be strong evidence for a specific deficit in the processing of high-level social information. Finally, it would be important to determine whether our participants show deficits in other precursors to ToM, such as gaze processing.

One interesting possibility is that different precursors will be impaired to different degrees depending on the extent to which they rely on the neural networks involved in ToM. For instance, gaze processing activates some of the brain regions also activated in ToM tasks. Action representation, however, may engage mainly different brain areas to ToM, such as those pertaining to the mirror system (Grèzes & Decety, 2001). For this reason, it is conceivable that gaze processing may be impaired in individuals with difficulties in ToM, whereas action representation could be spared. However, a recent study investigating the neural correlates of action prediction (Ramnani & Miall, 2004) showed that predicting somebody else's actions activates paracingulate cortex and STS, which are areas typically activated during mentalising. This suggests that the brain areas involved in ToM may have multiple functions ranging from the attribution of complex mental states to the representation of simple actions (Frith & Frith, 1999; Frith & Frith, 2001; Gallagher & Frith, 2003; Sebanz & Frith, 2004). fMRI studies in individuals with autism may prove useful to find out more about the link beween ToM and its putative precursors (cf. Cody, Pelphrey, & Piven, 2002).

The participants with autism in our study did not show any executive deficits with respect to response inhibition. They were able to inhibit responses to neutral cues in the go–nogo task, and to inhibit prepotent responses in the two-choice RT task. The performance in the go–nogo task replicates previous results obtained with the go–nogo paradigm. It is somewhat more surprising that the inhibition of prepotent responses was unimpaired. This may be due to the fact that the participants were very high functioning, but could also be related to the nature of the task. It could be that other types of prepotent responses, such as responses that are of a more affective nature, e.g., grasping something one really wants to have, may be more difficult to inhibit (Russell et al., 1991). Our results do not allow us to draw any conclusions about cognitive flexibility. Further testing would be needed to gain a more complete picture of the participants' executive functioning abilities.

Contrary to previous findings, we could not find any evidence for weak central coherence. A processing style characterised by weak central coherence could have manifested itself in two ways: On the one hand, the visual stimuli could have been processed locally rather than globally. On the other hand, the other person could have been ignored rather than integrated in action planning. Neither of the two were observed. This finding is also supported by the fact that performance on the Block Design Subtest of the HAWIE-R did not differ from the control group (Shah & Frith, 1993). Thus,

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[2] As mentioned before, there was one participant in our study who was not able to solve any ToM tasks. This participant did not show a significant joint compatibility effect in Experiment 1, but showed a rather large compatibility effect in Experiment 2.

we conclude that in our sample of individuals with autism, cognitive processing was not characterised by weak central coherence. It is tempting to speculate that the participants with autism were not action-blind because they were not context-blind. This applies to the visual processing level, where the processing of the irrelevant spatial dimension caused automatic response activation, and to the level of social information processing, where processing of the social context induced them to form a representation of the co-actor's task.

Additional direct testing of weak central coherence in our participants would be needed to evaluate this assumption in more depth. Also, we cannot fully exclude the possibility that deficits in central coherence and executive functioning were both present to some degree and obscured each other by yielding opposite effects. However, this possibility does not affect our conclusion that the other's task was represented. It is hard to see how the differential effect of the co-actor's task on individual action could be explained in terms of interference between weak central coherence and a deficit in executive functioning. Rather, it seems likely that high-functioning individuals with autism are surprisingly tuned in to others' actions.

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