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Metacognition of agency and theory of mind in adults with high functioning autism

Tiziana Zalla [a,*], David Miele [b], Marion Leboyer [c], Janet Metcalfe [d]

[a] Institut Jean Nicod, CNRS, Ecole Normale Supérieure, PSL Research University, Paris, France
[b] Department of Counseling, Developmental, and Educational Psychology, Boston College, Chestnut Hill, MA, USA
[c] INSERM U 955, IMRB & University Paris Est Creteil, AP-HP, Henri Mondor-Albert Chenevier Hospitals, Department of Psychiatry, Fondation FondaMental, French National Science Foundation, Creteil, France
[d] Department of Psychology, Columbia University, New York, NY, USA

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ABSTRACT

We investigated metacognition of agency in adults with high functioning autism or Asperger Syndrome (HFA/AS) using a computer task in which participants moved the mouse to get the cursor to touch the downward moving X's and avoid the O's. They were then asked to make judgments of performance and judgments of agency. Objective control was either undistorted, or distorted by adding turbulence (i.e., random noise) or a time Lag between the mouse and cursor movements. Participants with HFA/AS used sensorimotor cues available in the turbulence and lag conditions to a lesser extent than control participants in making their judgments of agency. Furthermore, the failure to use these internal diagnostic cues to their own agency was correlated with decrements in a theory of mind task. These findings suggest that a reduced sensitivity to veridical internal cues about the sense of agency is related to mentalizing impairments in autism.

1. Introduction

This article addresses the question of whether people with autism spectrum disorders (ASDs) exhibit difficulties in distinguishing between self-controlled and externally-controlled action, that is, whether they may exhibit abnormalities in their metacognition of agency. The ability to reliably monitor whether one is, oneself, controlling an action, or whether the action is being controlled or interfered with by forces or circumstances that are external, seems to be fundamental in establishing self-other boundaries. Difficulties in establishing and maintaining such boundaries between self and non-self could have many consequences, including impairments in understanding the perspective of another and in knowing that the perspective of another is different from one's own perspective – difficulties that are prominent in people with ASDs.

Russell (1996) proposed that an impairment in agency monitoring processes in individuals with ASDs might emerge as early as the second year of life. He suggested, as well, that an agency detection breakdown could impact the acquisition of theory of mind (ToM, i.e., the ability to attribute mental states to oneself and to others) (Premack & Woodruff, 1978) in ASDs, because mentalizing abilities centrally depend upon possessing a form of pre-theoretical self-awareness that self-agency-monitoring makes possible. This ability underpins the most basic processes needed for ToM, and hence deficits in one's own sense of agency may be deeply linked with ToM impairments (Russell, 1996).

* Corresponding author at: Institut Jean Nicod-CNRS, Ecole Normale Supérieure, 29 rue d'Ulm, 75005 Paris, France. Fax: +33 (0)1 44 32 26 99.
E-mail address: tiziana.zalla@ens.fr (T. Zalla).

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This proposal is consistent with what is known about the developmental trajectory of agency monitoring in normal children. Human infants are not initially endowed with either a fully mature ToM, or sense of agency. An elementary sensitivity to one's own agency, which arises in infants around 9–18 months of age (Johnson, 2003), is thought to be a developmental precursor of the ability to assign intentions to others and to be capable of making metacognitive judgments about one's own of agency. The experience of being the agent of one's own action, as compared to the experience of being an observer of an event caused by external sources, is constitutive of the self-other differentiation. Baldwin (1906) argued that for an infant to overcome adualism (the merging of objectivity and subjectivity), he or she must discover that data from the world are sometimes discrepant with his or her needs (i.e., that the nipple is not invariably there). It is the mismatch between the child's 'conative affective striving' and *what is there* that allows the child to begin to separate the self from the outside world, and that provides a precursor for the development of a self. Thus, the detection of discrepancy between one's own intentions and what happens (due to others or the world) allows the individual to begin to sort out the relation between the self and others as is needed for a formation of self-awareness at the most elementary level. Such discrepancy detection is at the core of a number of models concerned with people's sense of agency (described below). Any impairment in making a clear distinction between the self and others – i.e., partial perseveration of adualism – could result in (a) conflation of one's own perspective with that of the other including misattributions of agency, and in (b) difficulties in tasks, such as ToM tasks, in which it is necessary to appreciate that the other's beliefs or perspectives are different from one's own.

Pacherie (1997), too, has argued that agency monitoring and mentalizing deficits may be impaired, in tandem, in ASD. In her view, it is a specific aspect of agency monitoring that potentially gives rise to elementary self-knowledge and that is related to both metacognition of agency and mentalizing. It is not just the individual's prior intentions, per se, that are important, but rather their 'intention in action' (Searle, 1983) that allows the development of self-awareness. The 'intention in action' cue is the ongoing detection of potential discrepancy or lack of discrepancy between the outcome and the intention which indicates the effectiveness of the self's motor action during action performance and that conjoins self-awareness, agency judgments, and ToM. It is this cue that we tap – as the sensory motor discrepancy detection cue – in the present experiment.

Although the rationale for expecting a correspondence between an impaired sense of agency and diminished ToM in ASDs is clear, the empirical studies directed at this question – particularly at the agency question – are few and the results are mixed.

Considerable research points to a deficit in ToM among people with ASDs, including those with high functioning autism and Asperger Syndrome (HFA/AS). ASDs are neuro-developmental disorders that are characterized by qualitative impairments in communication, social interactions and stereotyped repetitive behavior (DSM-IV, American Psychological Association, 2000). Indeed, many researchers have regarded impairments in TOM, or in what is sometimes been called 'mentalizing', as the core deficit underlying ASDs (Baron-Cohen, 1989, 1995; Baron-Cohen, Leslie, & Frith, 1985; Frith, 1989; Leslie, 1987, 1991; Leslie & Roth, 1993). Adults with HFA/AS can pass first- and second-order mindreading tests (Dahlgren & Trillingsgaard, 1996), but they often may fail in more 'advanced' ToM tasks, based on the detection of sarcasm, irony or bluff (Happé, 1994). They also often fail to appreciate inappropriate or insensitive social comments, that is they do not understand Faux Pas (Baron-Cohen, O'Riordan, Stone, Jones, & Plaisted, 1999; Zalla, Stopin, Ahade, Sav, & Leboyer, 2009). The Faux Pas advanced ToM task will be used in the present study.

While a deficit in ToM is well established in studies of ASDs, the sense of agency has been less investigated. In the present study, we will first overview current ideas on how people are thought to be able to determine whether they are the agent controlling a phenomenon, and then turn to studies investigating this capability in participants with ASDs. The predominant theory explaining people's sense of agency is the Comparator Model (Frith, 2005; Frith, Blakemore, & Wolpert, 2000; Wolpert, Ghahramani, & Jordan, 1995) of motion control. One important component of this model is that people use an *efference copy* that incorporates an intention or plan of the action to predict the sensory consequences of a given motor command. This expectation or plan is compared, in real time, to the so-called *afference*, that is, the actual sensory-motor outcome (Wolpert et al., 1995). The matching process between central motor plans and the multisensory feedback signals (visual, tactile and proprioceptive) arising during action execution, together with the associated motor intention, is the crucial mechanism thought to both underlie the kind of delicate motor control exhibited by humans and a signal that is the basis for people's sense of agency. This matching process is tantamount to what Searle (1983) calls 'intention in action'.

Recent theories directed at people's metacognition of agency offer support for the idea that people use a variety of cues to make conscious judgments of agency. One of these cues could be the match/mismatch cue from the comparator model. Such a cue allows control of motor or other behavior and it can affect behavior at a level prior to awareness (Fourneret & Jeannerod, 1998; Georgieff & Jeannerod, 1998; Jeannerod, 1999; Sebanz, Bekkering, & Knoblich, 2006). However, the high-level metacognitive judgment process by which people are able to assess the extent of their control is thought to involve consciousness (Metcalfe, 2013; Metcalfe, Eich, & Miele, 2013; Synofzik, Vosgerau, & Newen, 2008), and to be reportable by the individual. Thus, there are two distinct components to agency: (1) an implicit 'feeling of agency' (FoA), mediated by lower-level, pre-reflective, sensori-motor processes that subserves action-processing, and which arises mainly from the match or mismatch between the efference copy and afference, and (2) an explicit or conscious 'judgment of agency', which is based, not only on a signal from this matching process but also on reflective or belief-like processes. These explicit metacognition of agency judgments can use but are not limited to using only the match/mismatch cue. Other cues can also contribute to these judgments. Importantly, some of the other cues that are utilized in the conscious judgments of agency are the perceived goodness of performance and the salience of reward (for example, see Metcalfe, 2013). These 'external' cues are not necessarily accurate with respect to the self/other distinction. For instance, performance can be accidentally good without the self being implicated in causing the good performance.

However, the discrepancy cues described in the comparator model (i.e., cues signalling a discrepancy between efference and afference) do provide the actor with diagnostic information concerning his or her own agency or lack of agency. In the experiment that follows these critical discrepancy cues are captured in the turbulence and lag conditions, which involve distortions in objective control. The individual's reliance on these diagnostic cues can be contrasted with his or her reliance on cues such as the perceived goodness of performance, which are not necessarily diagnostic of agency.

There are some indications – though few are direct or compelling – that there may be impairments in metacognition of agency associated with ASDs. This evidence is often indirect, and no previous studies have sought to distinguish whether the cues that people with ASDs are using are diagnostic or non-diagnostic. Prominent among the experiments providing indirect evidence is a study by Russell and Jarrold (1999) who found that children and adolescents with autism had difficulties remembering whether they or another person had performed certain actions and thus, unlike the comparison groups, were not better at recalling their own actions. Such a failure might have been a selective memory abnormality, but it might also have occurred because the children with ASDs did not adequately monitor and distinguish between what they had done and what the other had done in the first place (see, Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009). Note, though, that Hill and Russell (2002) failed to replicate this study, and that Williams and Happé (2009) also reported typical memory effects in participants with ASDs. Other studies, however, have shown – like the original Russell and Jarrold (1999) study – that ASDs are associated with smaller differences in memory than those shown by typical participants as a function of self-relevance (Hare, Mellor & Azmi, 2007; Millward, Powell, Messer, & Jordan, 2000; Toichi et al., 2002). Individuals with typical development remember and apparently give preferential processing to information that is self-generated, self-relevant, or self-enacted, whereas individuals with ASDs fail to accord such preferential treatment and sometimes cannot discriminate self-generated from the other-generated information (Millward et al., 2000; Toichi et al., 2002). It is possible that the ASD participants exhibit this deficiency because, as Zalla, Daprati, Chaste, Nico, and Leboyer (2010) hypothesized, they have a diminished sensitivity to internal agency cues (i.e., a deficit in metacognition of agency). Such diminished sensitivity would reduce the difference between observed and performed actions in memory. Consistent with this hypothesis, Zalla and collaborators reported that individuals with HFA/AS, when asked to recall self-performed actions, did not profit from performing the actions themselves to the same extent as did typically developed individuals and failed to encode personal events in the same way as a matched control group. However, while this reduced self-reference in ASDs is plausible, alternative interpretations have also been offered, including impaired episodic memory (Bowler, Gardiner, & Grice, 2000), delayed development of source monitoring abilities (Bowler, Gardiner, & Berthollier, 2004; Lind & Bowler, 2009) or difficulties in complying with the executive demands of various self-referential tasks (Hala, Rasmussen, & Henderson, 2005). Several other studies have more directly investigated the possibility that ASDs affect people's sense of agency. David et al. (2008) constructed a task in which participants were asked to distinguish between their own online action toward a target at the top of the screen and a 'computer' action toward the same target. This task, which would seem to be useful in directly assessing breakdowns in agency monitoring, showed comparable performance between ASD and control participants. There are, of course, many reasons why null results might have been obtained.

More recently, Sperduti, Pieron, Leboyer, and Zalla (2014) found positive evidence for impairment in ASDs on a different 'sense of agency' experiment. They tested individuals with ASDs and controls in an intentional binding task. Intentional binding refers to the finding, in individuals with typical development, of a decrease in perceived time between the onset of an action effect to the offset of the effect when one is, oneself, the agent who initiated the effect, as contrasted to when one observes the same events externally (see, Haggard, Clark, & Kalogeras, 2002; Haggard & Eimer, 1999; Moore & Haggard, 2008 for possible explanation of this effect). Whatever its explanation, this decrease in perceived time as a function of being the agent rather than being a mere observer is widely accepted as reflecting one's implicit sense of agency. In Sperduti et al. (2014) study, the participants with ASDs exhibited reduced intentional binding, suggesting an altered sense of agency. In summary, although some findings, then, suggest that there might be a deficit in the sense of agency in ASDs, the evidence is scanty, and whether there is a relation between deficits in metacognition of agency and impairments in ToM in ASDs is still unknown.

The present study investigated whether individuals with ASDs exhibit impaired metacognition of agency. We were especially interested in whether this purported impairment might be due to an inability to use those cues that provide valid information concerning their own control, while the use of goodness of performance cues might be intact.

Accordingly, in the present experiment, a group of adults with high functioning autism (HFA) or Asperger Syndrome (AS) and a group of matched control participants were asked to perform a computer-based agency task in which X's and O's streamed from the top of the computer screen. Participants moved the computer mouse, which in turn moved a box on a horizontal bar on the screen (see Fig. 1). As in previous studies (Kirkpatrick, Metcalfe, Greene, & Hart, 2008; Metcalfe, Eich, & Castel, 2010; Metcalfe et al., 2013; Metcalfe, Van Snellenberg, DeRosse, Balsam, & Malhotra, 2012), they were instructed to try to touch all of the falling X's with the box and avoid touching any of the O's. After engaging in this task for a short period of time they were asked to make judgments of their performance (JOPs) and judgments of their control or agency (JOAs).

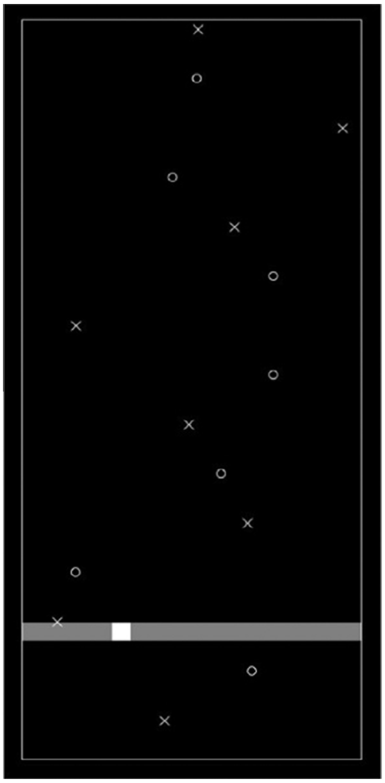

Fig. 1. A screen shot of the task. The participant moves the square on the grey bar at the bottom of the screen to 'catch' downward scrolling X's and avoid catching O's.

One reason that past research may sometimes not have shown an impairment in the sense of agency in ASDs, may have been because previous experiments had not specifically targeted the online discrepancy detection cue. The present task does so: It includes four conditions, two conditions in which turbulence and two conditions in which lag distorts the synchronous match between the intent and the outcome, or between the efferent and afferent copy, as posited by the 'Comparator Model'. The extent to which participants could objectively control the cursor using the mouse varied by conditions. In the control condition, there was a perfect correspondence (both spatially and temporally) between participants' movement of the mouse and the movement of the cursor on the screen. In the experimental conditions, participants' control of the cursor was altered by the introduction of a brief time Lag between the mouse and cursor movement (in conditions Lag 1 and Lag 2) or by the addition of turbulence or random noise to the cursor position (in conditions Turb 1 or Turb 2). Finally, the experiment included a Magic condition, in which X's disappeared whenever the cursor was near, but not necessarily touching them (thus, artificially inflating participants' performance). Within each block, four trials per condition were presented in a quasi-random order, with lag conditions always preceding turbulence conditions. This task allows us to investigate people's sensitivity to the diagnostic discrepancy cues implicated in the model by contrasting the experimental conditions to a control condition in which no such discrepancies are introduced.

We hypothesized that people with ASDs might fail to use the discrepancy cues, associated with the turbulence and lag conditions, in making judgments of agency. Even though such judgments occur at a conscious level, the disturbance might arise at the preconscious source of these sensorimotor cues – detection of discrepancy in the comparator model – leading to motor dysfluency and abnormalities across a wide range of behaviors in people with ASDs (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Importantly, as noted above, only some of the cues that are integrated into the judgment of agency are thought to be *diagnostic*, that is to actually allow distinguishing between the self and others (or a computer program) as the cause of the action. Other cues, including perceived goodness of performance, contribute to the conscious judgments of agency, but are not necessarily diagnostic of agency. Regression analyses conducted in past experiments using this paradigm with typical participants have shown that these diagnostic cues contribute to people's judgments of agency (Metcalfe et al., 2013). In contrast, patients with schizophrenia – a population known for difficulties in accurately ascertaining their own agency – fail to use these diagnostic cues in making judgments of agency, while, at the same time, they do use non-diagnostic cues such as perceived goodness of performance, to make JOAs (Metcalfe et al., 2012).

The final concern of the present research was with the possible relation, proposed by Russell (1996) and by Pacherie (1997), between abnormalities in the sense of agency and deficits in ToM in ASDs. In the present study, mindreading abilities were evaluated by using an advanced ToM task, the Faux-pas Recognition Task (Baron-Cohen et al., 1999). Previous studies using the Faux Pas recognition task (Baron-Cohen et al., 1999; Zalla et al., 2009) showed that individuals with high functioning autism have difficulty in reasoning about others' mental states and emotions, as exemplified by their performance on this test.

2. Method

2.1. Participants

Nineteen adults with a clinical diagnosis of high functioning autism (HFA) or Asperger Syndrome (AS) according to DSM-IV R (American Psychiatric Association, 2000), the ADOS (Lord et al., 2000) and ASDI (Asperger Syndrome Diagnostic Interview, Gillberg, Gillberg, Råstam, & Wentz, 2001) were recruited from Albert Chenevier Hospital in Créteil (see Table 1 for details). The inclusion criteria for the sample were based on retrospective parental information about the early language development of their child. All diagnoses were made by experienced clinicians and were based on clinical observations of the participants. Semistructured interview with parents or caregivers using the ADI-R (Autism Diagnostic Interview, Lord, Rutter, & Le Couteur, 1994) yielded scores in three content areas: [B] social interaction, [C] communication, and [D] repetitive and stereotyped behaviors, allowing the separate quantification of severity of the symptomatology. The cut-off points for these domains are 10, 8, and 3, respectively. All participants scored above the cut-off points.

Nineteen comparison participants (CP) with typical development volunteered to match the clinical group with respect to age, IQ and gender (see Table 1 for details). Prior to their recruitment, the comparison participants were screened to exclude anyone with a history of psychiatric or neurological disorders. All participants were native French speakers, and had normal/corrected to normal vision.

Participants received basic neuropsychological screening, which included Verbal and Performance IQs (WAIS-III, Wechsler, 1997). All participants had an IQ above 70. Overall, individuals with HFA/AS did not differ from the comparison participants on gender, chronological age (t-test: $t(36) = -1.14$, $p = .25$), education (t-test: $t(36) = -0.66$, $p = .51$), IQ level (Full-scale, Verbal and Performance: t-test: $t(36) = 0.98$, $p = .33$; $t(36) = 0.63$, $p = .52$; $t(36) = 1.5$, $p = .14$). Participants with HFA/AS scored significantly higher in Autistic Quotient (t-test: $t(36) = -8.4$, $p < .0001$) and significantly lower in the Faux-pas Recognition task ($t(36) = 3.59$, $p = .001$) relative to the comparison group, consistently with what is expected from the clinical presentation of the syndrome (see Table 1). The Faux Pas is an advanced ToM test consisting in a series of stories describing situations in which a speaker says something that might hurt or is unpleasant to the listener, although the speaker never intended this effect.

The present research was approved by the local Ethical committee (Inserm, C07-33). All participants signed informed consent before volunteering for this study. The investigation was conducted according to the principles expressed in the Declaration of Helsinki.

2.2. Procedure

Participants were run individually through the experiment on iMac computers, which they controlled using a mouse and mouse pad. All instructions were presented on the computer in audio recorded and written form. At the beginning of the experiment, participants received the following instructions in French:

> "Throughout this experiment you are going to play a game in which you will use the computer mouse to move a box on a grey track. Your job is to touch all of the X's as they come into range and to avoid touching any of the O's. After each trial, you will be asked to assess your performance. If you felt you got all of the X's, and avoided all of the O's, you should click to the far right of the blue bar, indicating everything correct. If you felt you got none of the X's, and touched all of the O's,

Table 1
Means (and standard deviations) of demographic and clinical data.

	HFA/AS	CP
N (*M*:*F* ratio)	16:3	15:4
Age	28.8 (7.1) (range = 20–45)	26.4 (6.1) (range = 20–43)
Education	13.6 (3.3)	14.1 (2.4)
ADI [B,C,D]†	17.6 [6.8]; 11.4 [6.6]; 6.4 [3.1]	
Full-scale IQ	96.3 (19.8)	101.2 (7.5)
Verbal IQ	100.6 (18.9)	103.6 (8.4)
Performance IQ	91.5 (20.1)	98.8 (7.7)
Autism Quotient*	34.5 (7.5)	14.7 (6.4)
Faux Pas Score*	35.3 (13.2)	50.3 (7.6)

Note: Data from three HFA/AS and four control participant were missing for the Faux Pas test.
† [B] = reciprocal social interaction, [C] = communication, [D] = stereotyped behaviors.
* Difference between groups is significant at $p < .002$.

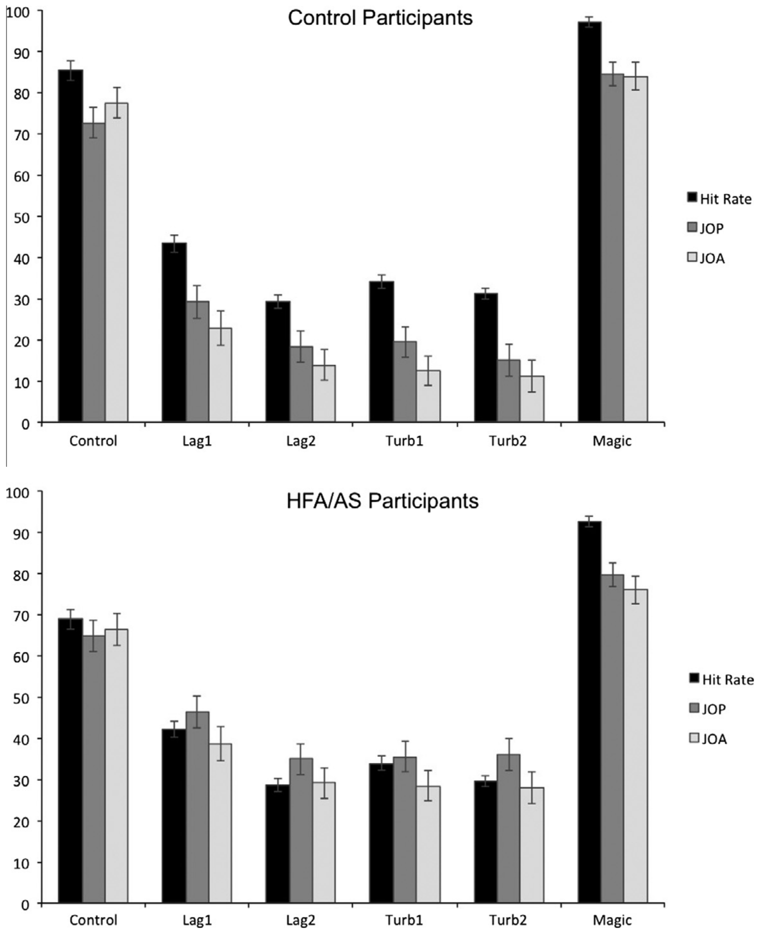

Fig. 2. Mean hit rate, judgment of performance (JOP), and judgment of agency (JOA) by condition for control participants and participants with HFA/AS.

then you should click to the far left, indicating nothing correct. You may also click anywhere in between. You will also be asked to assess how in control you felt. If you felt you were in complete control, click to the far right of the red bar. If you felt that you had no control, click to the far left. You may also click anywhere in between."

After receiving these instructions, participants practiced both playing the game and making judgments. The practice trials were the same as experimental trials in the control condition (see below). During each 15 s trial, the X's or O's that streamed down the screen immediately disappeared if the participant touched them with the cursor, but continued to stream below the mouse track if the participant did not touch them (Fig. 1). Additionally, the computer emitted a distinctive *beep* sound each time an X was touched (indicating a hit) and a *boop* sound when an O was touched (indicating a false alarm). After each practice trial, participants were asked if they wanted to complete an additional practice trial. Once they declined, participants practiced making judgments of performance (JOPs) and judgments of agency (JOAs).

Participants' responses for the two types of judgments were coded in the same manner by using a visual analogue scale and the participants could drag the slider to any point along a bar with their mouse. When the slider was positioned to far left of the bar, the response was coded as 0; when it was positioned to the far right, the response was coded as 100, with values in between being assigned their appropriate value on a linear scale. This slider bar for the performance judgments was blue. The slider bar for the agency judgments was red. The order of the judgments for both practice and experimental trials (i.e., whether the first judgment was a JOP or JOA) was counterbalanced across participants. The experimenter made sure that the participant understood how the scale worked and what the difference between these two types of judgments were by having the participant report what each judgment meant, during the practice trial. When participants finished practicing 'judgment of performance' and 'judgment of agency', they were asked if they wanted to practice it again. Once they declined additional practice and affirmed that they were ready to begin, the task began. Participants completed two blocks of 24 experimental trials (except for one participant with HFA/AS, who completed only one block). At the end of the study, participants were questioned about their experience and thanked for their participation.

2.3. Design

The experiment included six within-subjects conditions: a Control condition in which the participant had perfect control of the cursor using the mouse; a short Lag condition (Lag 1) in which movement of the cursor on the screen lagged the participant's movement of the mouse by 250 ms; a long Lag (Lag 2) condition in which movement of the cursor lagged the participant's movement of the mouse by 500 ms; a small turbulence (Turb 1) condition in which discrepancies between mouse and cursor movement from the Lag 1 condition were randomly reintroduced by the program as noise (see below); a large turbulence (Turb 2) condition in which similar discrepancies from the Lag 2 condition were reintroduced. In addition, a Magic condition, in which X's disappeared whenever the cursor was near, but not necessarily touching them (thus, artificially inflating participants' performance) was included. Following Metcalfe et al. (2012) 's study with patients with schizophrenia, we included the magic condition – which participants enjoyed and on which they performed very well. Within each block, four trials per condition were presented in a quasi-random order, with lag conditions always preceding turbulence conditions.

The amount of noise in the turbulence conditions was matched with the amount of discrepancy between the mouse and cursor movement in the lag conditions. This was accomplished by measuring the discrepancy between the mouse position and the cursor position at roughly 17 ms intervals during a lag trial and then *randomly* adding these difference scores to the cursor position at 17 ms intervals during a subsequent turbulence trial. This added noise was smoothed to prevent sudden jerks. As a result of the discrepancy-matching algorithm, the total amount of discrepancy (i.e., the sum of the differences between mouse and cursor position at each 17 ms interval over the entire 15 s trial) was the same across lag and turbulence trials. This made it possible to treat type of discrepancy (Lag vs. Turb) and amount of discrepancy (short vs. long) as separate factors. The difference between the two types of discrepancy was that, in the turbulence condition, the discrepancy between the mouse position and cursor position was not related to the participant's movement of the mouse on that trial; whereas, in the lag condition, the discrepancy directly corresponded to the participant's movement of the mouse at 250 or 500 ms earlier in the trial. In the control condition (which is used as a baseline) and the magic condition, there was no discrepancy between the cursor position and the mouse position.

The two metacognitive dependent variables of central interest were people's judgments of performance (i.e. their judgments of success at touching the Xs and avoiding the Os) and their judgments of agency (i.e. their judgments of how much control they thought they had during the game). Both were measured on an analogue scale coded from 0 to 100. We also computed actual performance in terms of hit rate (i.e. the proportion of times the person touched Xs that appeared on the screen), false alarm rate (i.e. the proportion of times the person touched Os), and *d*' (i.e., the person's success in discriminating between Xs and Os using the cursor), and we measured the overall amount of mouse movement on each trial.

3. Results

Before describing the main results of interest, namely, what cues people use to determine their JOA (see Fig. 3), and how the use of these cues relates to their performance on the ToM test (Fig. 4), we will first outline the underlying basic motor performance, JOP, and JOA results.

Motor performance. Hit rate, false alarm rate, and *d*' are reported in Table 2. As in past experiments using this paradigm, hit rate and *d*' were highly correlated (CPs [$r = .95$]; HFA/AS participants [$r = .94$]). In addition, the mean correlation between false alarm rate and participants JOAs ($r = -.47$) was substantially weaker than the mean correlation between hit rate and JOAs ($r = .82$; $t(37) = 32.60$, $p < .001$). We submitted each of the performance measures (hit rate, false alarm rate, and *d*') to separate 2 (Group: HFA/AS, CP) x 6 (Condition: Control, Lag 1, Lag 2, Turb 1, Turb 2, Magic) mixed ANOVAs with repeated

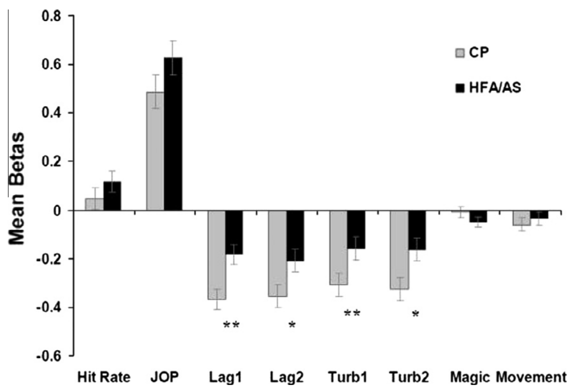

Fig. 3. Mean betas predicting judgments of agency by group and condition. Beta were derived from a series of within-subject regression analyses that included hit rate, JOP, Turb1, Turb2, Lag1, Lag2, Magic, and total movement as predictors. Error bars represent standard errors. $^{*}p < .03$; $^{**}p = .01$.

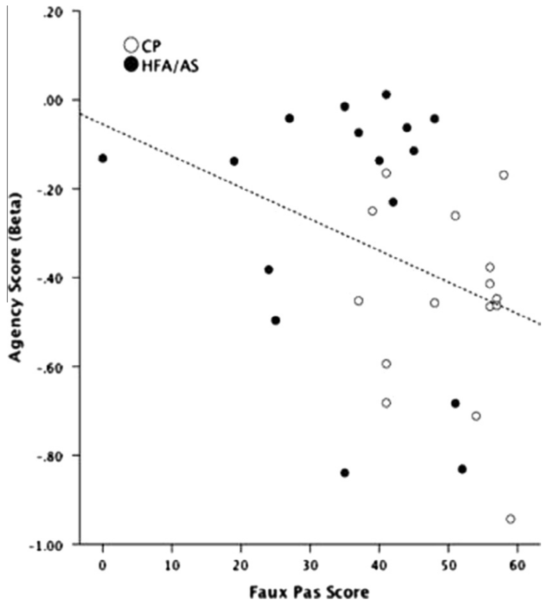

Fig. 4. Correlation between scores on the 'faux pas' ToM test and summary agency betas, which indicate the extent to which each participant based their JOAs on diagnostic discrepancy cues (i.e., Lag and Turb).

Table 2
Means (and standard deviations) for performance measures.

Measure	Condition					
	Control	Lag 1	Lag 2	Turb 1	Turb 2	Magic
HFA/AS participants						
Hit Rate	68.94 (11.97)*	42.21 (7.57)	28.61 (6.06)	33.91 (7.17)	29.60 (6.45)	92.59 (6.85)*
False alarm rate	7.10 (4.47)†	12.90 (5.03)†	15.85 (4.82)	18.16 (3.48)	18.88 (3.80)	6.08 (4.92)
d′	2.00 (.50)*	.97 (.33)	.46 (.29)	.51 (.30)	.36 (.30)	2.91 (.36)*
Control participants						
Hit rate	85.41 (9.31)*	43.32 (10.29)	29.20 (7.40)	34.14 (7.36)	31.20 (5.50)	97.18 (3.90)*
False alarm rate	4.70 (3.22)†	15.44 (3.25)†	14.93 (4.01)	17.51 (4.73)	19.38 (3.32)	4.16 (2.63)
d′	2.61 (.38)*	.87 (.39)	.48 (.33)	.55 (.34)	.39 (.23)	3.12 (.16)*

Note: Symbols indicate significant or marginally significant group differences for a particular measure within a particular condition.
* $p < .05$.
† $p < .10$.

measures on the last factor. For both hit rate and *d'*, we found significant main effects of Condition, (*ps* < .001), such that participants performed better in the Magic condition than in the Control condition, (*ps* < .001), and better in the Control condition than in the Lag and Turb conditions (*ps* < .001). There were also significant main effect of Group, (*ps* < .05), such that overall participants with HFA/AS performed worse than CP. However, these effects were qualified by significant interactions (*ps* < .001). Uncorrected post hoc tests showed that participants with HFA/AS performed significantly worse than CP in the Control (*ps* < .001) and Magic conditions (*ps* = .02), but not in the Lag and Turb conditions (*ps* > .41). The pattern of results was similar, but slightly different for false alarm rate. The main effect of Condition was significant (*p* < .001), such that participants performed worse in the Lag and Turb conditions than in the Control and Magic condition (*ps* < .001). However, the main effect of Group was not significant (*p* = .56), although the interaction was at significance after Greenhouse-Geisser correction (*p* = .05). Post-hoc tests showed that participants with HFA/AS had a marginally higher false alarm rate in the Control condition (*p* = .07), but a marginally lower rate in the Lag1 condition (*p* = .07). They did not differ in any of the other conditions (*ps* > .14).

Judgments of performance. We examined group differences in JOPs by submitting them to a 2 × 6 mixed ANOVA. As shown in Fig. 2, there was a main effect of Condition for JOPs ($F(5, 180) = 222.05$, $p < .001$, $\eta_p^2 = .86$). Participants judged that they performed better in the Magic condition than in the Control condition ($t(36) = 8.26$, $p < .001$), and better in the Control condition than in the Lag and Turb conditions (*ps* < .001). There was also a significant main effect of Group, ($F(1, 36) = 5.26$, $p = .03$, $\eta_p^2 = .13$): participants with HFA/AS reported higher judgments of performance overall than did CP. These effects were qualified by a significant interaction ($F(5, 180) = 14.61$, $p < .001$, $\eta_p^2 = .29$). Post-hoc tests showed that HFA/AS participants' judgments of performance were the same as those of the CPs in the Control ($t(36) = 1.48$, $p = .15$) and Magic, ($t(36) = 1.21$, $p = .23$) conditions, but HFA/AS's JOPs were higher in both Lag (Lag 1: $t(36) = -3.08$, $p = .004$; Lag 2: $t(36) = -3.09$, $p = .004$) and Turb (Turb 1: $t(36) = -3.10$, $p = .004$; Turb 2: $t(36) = -3.81$, $p < .001$) conditions, as compared to CP's JOPs.

Relation of judgments of performance to motor performance. To examine the accuracy of participants' JOPs (i.e., the within-participant relationship between perceived and actual performance across trials), we computed Spearman correlations (to account for non-normal distributions of trials within participants) between JOPs and all three performance outcomes (hit rate, false alarm rate, and d') for each participant and then applied Fisher's *r*-to-*Z* transformation to normalize the distribution of the correlations (Myers & Sirois, 2006). These correlations were significantly different from 0 in all cases. However, the mean correlations for both hit rate and d' were significantly higher for CP ($r_s = .86$ in both cases) than for HFA/AS participants ($r_s = .75$ & .74, $ts > 2.51$, $ps < .02$). The mean correlation for false alarm rate was slightly more negative for CP ($r_s = -.55$) than for HFA/AS participants ($r_s = -.46$), though this difference was not significant ($p = .30$).

Judgments of agency. We examined group differences in JOAs by performing a 2 × 6 mixed ANOVA. As shown in Fig. 2, the main effect of Condition that we observed for hit rate and JOPs also emerged for JOAs ($F(5, 180) = 242.80$, $p < .001$, $\eta_p^2 = .87$). That is, participants reported having more control in the Magic condition than in the Control condition ($t(36) = 5.11$, $p < .001$), and more control in the Control condition than in the Lag and Turb conditions ($ps < .001$). There was also a marginally significant main effect of Group ($F(1, 36) = 3.06$, $p = .09$, $\eta_p^2 = .08$), such that participants with HFA/AS reported having higher levels of control overall than did CP. These effects were qualified by a significant interaction ($F(5, 180) = 13.86$, $p < .001$, $\eta_p^2 = .28$). Post-hoc comparison analyses showed that although, compared to CP, participants with HFA/AS reported significantly lower levels of control in the Control condition ($t(36) = 2.07$, $p = .045$) and equivalent levels of control in the Magic condition ($t(36) = 1.64$, $p = .11$), they reported *higher* levels of control in the Lag (Lag 1: $t(36) = -2.68$, $p = .01$; Lag 2: $t(36) = -2.85$, $p = .007$) and Turb (Turb 1: $t(36) = -3.14$, $p = .003$; Turb 2 = $t(36) = -3.03$, $p = .005$) conditions.

Cues to agency. To investigate which factors contributed to participants' JOAs, we submitted each participant's judgments to an initial within-subject regression analysis in which JOPs, Lag1, Lag2, Turb1, Turb2, and Magic were entered as simultaneous predictors. This preliminary set of regression analyses was designed to closely replicate past research on the agency judgments of schizophrenic patients (Metcalfe et al., 2012, 2013). Lag 1, Lag 2, Turb 1, Turb 2, and Magic were dummy-coded, with 0 indicating that the manipulation was absent on a particular trial and 1 indicating that the manipulation was present.

After conducting the within-subject regression analyses, we submitted the resulting beta coefficients to a series of within group, one-sample *t*-tests which showed that, for both groups, the mean JOP beta was significantly positive (i.e., JOPs were positively correlated with JOAs, $ps < .001$), while the betas for Lag 1, Lag 2, Turb 1, and Turb 2 were significantly negative (i.e., the presence of Lag and Turb were associated with decreases in JOAs, $ps < .002$), and the mean betas for Magic was not significantly different from zero ($ps > .27$).

Importantly, between group, independent samples *t*-tests tests showed that although there were no group differences in betas for JOP ($t(36) = -1.59$, $p = .12$), Magic ($t(36) = .53$, $p = .60$), or Turb 2 ($t(36) = -1.60$, $p = .12$), HFA/AS participants' betas were significantly weaker (i.e., less negative) than control participants' betas in the Lag 1 ($t(36) = -2.24$, $p = .03$), and Lag 2 ($t(36) = -2.12$, $p = .04$), as well as in the Turb 1 ($t(36) = -2.10$, $p = .04$) condition.

Next, we conducted a second set of within-participant regression analyses, shown in Fig. 3, in which Hit Rate, JOPs, Lag 1, Lag 2, Turb 1, Turb 2, Magic, and Movement were entered as simultaneous predictors. The purpose of this second set of analyses was to incorporate additional predictors that may partly account for the mean JOA in each group. We included Hit Rate as a predictor because there were significant differences in performance between the two groups (see above). Although JOPs and Hit Rate were significantly correlated, JOPs did not account for the entire effect of Hit Rate on JOAs—that is, Hit Rate was significantly correlated with JOAs even after controlling for JOPs ($r_p = .30$). Movement (i.e., the number of pixels that the participant moved the cursor to the left or to the right on each trial) was included as a predictor in order to partially account for the possibility that group differences in JOAs were due to differences in how CP and HFA/AS participants used the mouse to control the cursor.

After conducting the within-subject regression analyses, we submitted the resulting beta coefficients to a series of within group, one sample *t*-tests.[1] As shown in Fig. 4, the results were very similar to the results of the previous analysis: The JOP betas for both groups were significantly positive (i.e., JOPs were positively correlated with JOAs, $ps < .001$), and the betas for Lag 1, Lag 2, Turb 1, Turb 2 were significantly negative (i.e., the presence of Lag and Turb were associated with decreases in JOAs, $ps < .009$). The significance of the mean betas for Hit Rate, Magic, and Movement varied by group: the Hit Rate and Magic betas were significant and marginally significant for HFA/AS participants ($ps = .03$ & .08, respectively), but not significant for CP ($ps > .24$). The mean Movement beta was significant for CP ($p = .007$), but not for HFA/AS participants ($p = .29$).

Most importantly, between-groups, independent samples *t*-tests showed that although there were no group differences in betas for Hit Rate ($t(36) = -1.10$, $p = .28$), JOP ($t(36) = -1.42$, $p = .16$), Magic ($t(36) = 1.39$, $p = .17$) or Movement ($t(36) = -.62$, $p = .54$), HFA/AS participants' betas were significantly less negative than CP's betas in the conditions related to the discrepancy cue: the Lag 1 ($t(36) = -2.58$, $p = .01$), Lag 2 ($t(36) = -2.45$, $p = .02$), Turb 1 ($t(36) = -2.68$, $p = .01$), and Turb 2 ($t(36) = -2.22$, $p = .03$) conditions.[2]

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[1] Because Hit Rate was strongly correlated with JOPs, this predictor showed signs of multicollinearity (i.e., tolerance < .1 and VIF > 10) for 10 of the CPs and 4 of the HFA/AS participants. Thus, estimates of Hit Rate in the above model may have been somewhat imprecise.

[2] To make sure the results did not vary depending on which performance outcomes was includes in the within-participant regression analyses, we conducted one set of analyses that included false alarm rate in addition to hit rate and another set of analyses that included d' instead of hit rate. Tests of the betas revealed the same pattern of group differences as found in the analysis that included only hit rate. There were no group differences for false alarm rate or d'.

Relation of metacognition of agency and ToM. The group with HFA/AS scored significantly lower than the CP ($t(36) = 3.59$, $p = .001$), on the Faux Pas test, consistent with what is expected from the clinical presentation of the syndrome (see Table 1). To determine whether participants' Faux Pas total score was correlated with their sense of agency, we first computed a summary beta that indicated the extent to which each participant *used the diagnostic discrepancy cues* appropriately when making JOAs across conditions. To do this, we conducted an additional set of within-participant regression analyses, similar to the ones described above. However, instead of including each of the conditions (i.e., Lag 1, Lag 2, Turb 1, and Turb 2) as separate predictors, we regressed participants' JOAs onto a single dummy-coded agency variable (Lag 1, Lag 2, Turb 1, and Turb 2 = 1, all other conditions = 0), as well as their JOPs. The standardized beta coefficients for the agency variable were use in all subsequent correlation analyses. As shown in Fig. 4, there was a significant negative correlation between Faux Pas scores and agency betas when collapsing across groups ($r = -.35$, $p = .05$). The better participants performed on the Faux Pas task, the more they picked up on diagnostic discrepancy cues during the game.

4. Discussion

The present study indicated good accuracy level in metacognitive judgements of performance (JOPs), along with a diminished use of the diagnostic sensori-motor cues in making metacognitive judgments of agency (JOAs) in adults with HFA/AS. While all participants grounded their judgments of agency on judgments of performance (i.e., the perceived goodness of performance), participants with HFA/AS showed an underreliance on the internal *diagnostic* agency cues generated during the experimental manipulations. The extent of underreliance on these internal sensory motor cues correlated with poor performance on the Faux Pas task that provided an evaluation of the individual's mentalizing abilities.

The idea of impairments in metacognition of agency in HFA/AS, which might be related to problems in mentalizing, supports the theoretical positions forwarded by Russell and Jarrold (1999) and Pacherie (1997). On this matter, previous findings are scanty and inconsistent. For example, Spengler, Bird, and Brass (2010) found a significant correlation between performance in the imitation-inhibition task and a ToM task, suggesting that disturbance in action monitoring is related to mentalizing abilities in individuals with ASDs. In addition, in an associated imaging study, decreased performance on imitative control was associated with reduced activity in medial prefrontal cortex and temporoparietal junction, regions that are often involved in mental state attribution. In contrast, Santiesteban, Banissy, Catmur, and Bird (2012) reported no interaction between tasks eliciting on-line control of self-other representations and the tasks which required to attribute mental states.

The specificity of the agency deficit to particular internal sensory motor diagnostic cues (that are the so-called 'intention in action' cues), supported by the present study, bolsters Pacherie's contention that this particular aspect of agency assessment is foundational for people's understanding of the boundaries between self and other, for the development of the perspectival self, and for the kind of projection of that perspectival self that is needed for mentalizing and ToM abilities. The finding that the difference in the agency judgments of people with ASDs and typical participants is restricted to the use of one particular kind of cue – internal sensory motor cues that indicate a discrepancy – also might help to explain why some of the earlier studies that investigated agency judgments in people with ASDs failed to find evidence for impairment. If the experiment did not pinpoint the right cues, but instead used a task in which the participant, whether ASD or not, could make the judgments based only on external cues, such as the goodness of performance, or the amount of reward given, then no differences between the participants with ASDs and typical participants would be expected. This blindspot shown by the ASD participants for the diagnostic internal sensorimotor cues to agency may reflect a subtle impairment in (a) the formation of internal predictions via an efference copy, (b) the comparison of the predicted and actual state, or (c) the processing and interpretation of the comparator output.

The present findings do not allow us to say which of these options obtains. Indeed, it is even possible that the pattern seen in the present data is due to a chronic inability of the ASD participants to understand the word 'agency' or 'control' in the same way as do typical participants. However, if it was the case that the meaning of the word 'control', for a person with ASD, does not include recourse to cues that are internal, one would have to consider how participants with typical development came to understand the linguistic domain of the word to include these internal diagnostic cues, and why such a process did not occur in the experience of the ASD participants.

The present results also suggest that despite showing a good degree of metacognitive accuracy, participants with HFA/AS were slightly less accurate in their JOPs than CP. Nevertheless, metacognitive correlations were very high. For comparison to previous studies using the same paradigm (see Metcalfe et al., 2010), the Pearson correlations between JOP and hit rate were .89 for CP and .77 for HFA/AS participants, about as high as those shown by elders (.81) and higher than those of preadolescent children (.67). Theses values were well above chance indicating that HFA/AS participants were not exhibiting a substantial deficit in metacognition concerning their performance.

These findings are consistent with previous studies reporting that individuals with autism perform remarkably well on a metamemory task (Farrant, Blades, & Boucher, 1999; Wojcik, Allen, Brown, & Souchay, 2011; Wojcik, Waterman, Lestié, Moulin, & Souchay, 2014). In fact, such judgments, typically, do not need to make reference to the person, either self or other, who was the source of the action. The present results go further, though, in that they also do not support the contention that participants with ASDs will always exhibit an impairment on metacognition of agency, relative to their control group. Instead, they are expected to show a difference from individuals with typical development only on agency tasks that require the use of a particular subset of the cues that are usually used to make agency judgments: the internal sensory motor cues to agency.

Interestingly, in the present study participants with HFA/AS also exhibited slightly worse motor performance than comparison participants in the Control and Magic conditions. A previous study by Russell and Jarrold (1998) suggested that insufficient monitoring of self-performed actions in autism could be associated with an impaired ability to relate motor commands to their visual outcomes by means of visual action schemata. Moreover, atypical action kinematics characterized by jerky arm movements, greater acceleration and velocity (Cook, Blakemore, & Press, 2013), difficulties in anticipating the sensory consequences of one's motor output (Cattaneo, Boria, & Monti, 2007), as well as in motor planning (Fabbri-Destro, Cattaneo, Boria, & Rizzolatti, 2009; Hughes, 1996) and action prediction (Zalla, Labruyere, Clément, & Georgieff, 2010; Zalla, Labruyere, & Georgieff, 2006) have been reported elsewhere in individuals with ASD. It is possible, then, that our finding that people with ASDs fail to recruit the sensory motor cues to make their judgments of agency comes about because those sensory motor cues are, themselves, unreliable.

Such a view is consistent with recent Bayesian cue integration models of agency that propose that the sense of agency relies on the weighted integration of multiple internal and external agency cues together with prior beliefs. These models indicate that the relative influence of the cues will be determined by their reliability, though how that reliability is determined is not always obvious, as in the present case. Under normal conditions, both external and internal sources of information are used to determine the sense of agency (Frith, 2013; Metcalfe, 2013; Moore, Wegner, & Haggard, 2009; Synofzik & Vosgerau, 2012; Synofzik et al., 2008; Wegner, Sparrow, & Winerman, 2004; Wegner & Sparrow, 2004). The weighting of external cues may increase when the reliability of internal sensorimotor and proprioceptive information decreases (Moore & Haggard, 2008; Moore et al., 2009). The data presented here are broadly consistent with this argument in the following sense. It is possible that individuals with ASDs learn to rely more on external information (such as their perception of performance) at the same time downplaying their use of internal signals (such as the discrepancy cues) because, for them, those internal signals are unreliable. In contrast, for typical participants the internal signals are undistorted and reliable, and so they use them.

Our data are also consistent with the related idea that individuals with HFA/AS rely mostly on visual, rather than proprioceptive, information when asked to make agency judgments (see Synofzik, Vosgerau, & Voss, 2013 for a similar idea applied to schizophrenia). This visual preference idea might relate to results showing that the memories of participants with ASDs often have a "perspective-free" character (Russell & Jarrold, 1999) and are predominantly or even exclusively visual in content (Hulburt, Happé, & Frith, 1994).

5. Conclusions

The present study reveals that, despite a good degree of metacognition of agency, participants with HFA/AS have a diminished agency monitoring. In making their judgments of agency, they used external cues such as goodness of performance to the same extent as did control participants, but they relied to a lesser extent than did control participants on the particular internal sensory motor cues that are diagnostic of agency. In addition, lower performance in ToM was correlated with reduced diagnostic agency beta scores: the more participants picked up on diagnostic cues to agency – whether the self was indeed in control or not – the better they were at inferring others' intentions in social situations. These findings support the notion that there is a causal and functional relation between ToM and the sense of agency.

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