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Absence of spontaneous action anticipation by false belief attribution in children with autism spectrum disorder

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Abstract

Recently, a series of studies demonstrated false belief understanding in young children through completely non-verbal measures. These studies have revealed that children younger than 3 years of age, who consistently fail the standard verbal false belief test, can anticipate others' actions based on their attributed false beliefs. The current study examined whether children with autism spectrum disorder (ASD), who are known to have difficulties in the verbal false belief test, may also show such action anticipation in a non-verbal false belief test. We presented video stimuli of an actor watching an object being hidden in a box. The object was then displaced while the actor was looking away. We recorded children's eye movements and coded whether they spontaneously anticipated the actor's subsequent behaviour, which could only have been predicted if they had attributed a false belief to her. Although typically developing children correctly anticipated the action, children with ASD failed to show such action anticipation. The results suggest that children with ASD have an impairment in false belief attribution, which is independent of their verbal ability.

Keywords: Autism Spectrum Disorder, Theory of Mind, Anticipation, Eye Tracking

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Introduction

Effective and efficient understanding and prediction of others' action is critical for social interaction and communication and cognitive mechanisms underlying effective social interaction and communication have been central to investigations within various fields of cognitive science, including developmental psychology and developmental cognitive neuroscience. In a groundbreaking paper, Premack and Woodruff (1978) proposed that chimpanzees, like humans, infer others' mental states such as desires, intentions and beliefs, and predict and control others' actions based on attributed mental states. They coined the term 'Theory of Mind' for this cognitive mechanism. However, because in most cases, action prediction based on a theory of mind appears the same as a prediction made with a learned behavioural association, the original studies reported in Premack and Woodruff (1978) were not conclusive as to whether chimpanzees really have theory of mind. To solve this problem, Dennett (1978) proposed an ingenious experimental paradigm, known as the false belief task (Wimmer & Perner, 1983; Baron-Cohen, Leslie & Frith, 1985). In this false belief task, a desirable object, usually hidden in a container, is displaced to another container while a protagonist is away. In this situation, theory of mind predicts that the protagonist should go to the previous location of the object because she is unaware of the displacement and thus has a false belief about the current location of the object. In contrast, a behavioural association would predict that the protagonist should go to the current location of the object based on an association between the protagonist and the object (Dennett, 1978; for an alternative view, see also Perner & Ruffman, 2005). Since then, this false belief task has been extended for use also in the fields of developmental psychology, psychiatry and psychopathology. In these developmental studies, the false belief task is often treated as "the litmus paper" of theory of mind, and sometimes even assimilated to correspond to the full capacity of theory of mind skills (e.g. Astington & Jenkins, 1999; Zelato, Jacques, Burack & Frye, 2002), despite tapping only one aspect of theory of mind (i.e. attributions of false belief). This may be because of its lower susceptibility to type-I error (Dennett, 1978), its capacity to capture developmental trajectory (e.g. Happé, 1995), and/or the impact of the seminal study of Baron-Cohen and colleagues (1985), which reported that children with autism, who suffer from severe impairment in social interaction and communication, do not pass the false belief task.

Since Baron-Cohen et al. (1985), much evidence has accumulated supporting the proposal that children with Autism Spectrum Disorder (ASD) show atypical development of the capacity for 'theory of mind' (Baron-Cohen, 1995). The most consistent finding is that children with ASD, before the verbal mental age of 11 years, do not pass various versions of the 'false-belief' task (Happé, 1995). Whereas typical 4-year-olds correctly anticipate others' behaviour based on the attribution of a false belief, children with ASD, at the same mental age or even higher, incorrectly predict behaviour based on reality, without taking into account the other person's epistemic states (Baron-Cohen et al., 1985). This result was interpreted as evidence that children with ASD at the verbal mental age of 4 years fail to represent others' epistemic mental states, or at least fail to do so when others' mental states are different from the child's own.

However, two decades of empirical studies and theoretical debate have revealed that standard false belief tasks suffer from at least two major problems that could affect the interpretation of the results (Birch & Bloom, 2003; Bloom & German, 2000) The first limitation of the standard false belief task is that individuals with ASD of higher verbal skills, such as older children and adults with Asperger Disorder or high-functioning autism, pass a false belief test (Abell, Happe, & Frith, 2000; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). However, despite their success on standard false belief tasks, they still exhibit problems in less-structured theory of mind tasks, such as attributing mental states to geometric shapes on the basis of their movement pattern (Abell et al., 2000), or to other people merely from looking at photographs of their eyes (Baron-Cohen et al., 1997; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). The second limitation is that, beyond theory of mind abilities, most false belief tasks require additional cognitive skills other than theory of mind for successful performance. To answer the questions correctly, children need to (1) remember the whole sequence of the story, (2) inhibit their knowledge about the actual location of the object and, above all, (3) correctly interpret the verbal questioning of the experimenter. Such additional task demands may prevent both young typically developing children, and children with ASD, from answering the questions correctly because of their known difficulty in executive attention (Minshew, Goldstein, & Siegel, 1997; Ozonoff, Pennington, & Rogers, 1991), or often poor linguistic abilities (American Psychiatric Association, 2000; Tager-Flusberg, 1981, 2000, 2001). Thus, it is not clear whether individuals with ASD, even when they pass the standard false belief task, understand the minds of others in the way that typically developing individuals do.

To address this question, we used a novel, non-verbal false belief task, building on a paradigm that was originally developed for studying infant cognition and has fundamentally changed our understanding of the development of mental state attribution. Onishi and Baillergeon (Onishi & Baillargeon, 2005) found that typically-developing 15-months-olds were 'surprised' when an agent, who had not seen a toy being moved, nevertheless searched correctly for it, suggesting that they attributed a false belief to her and expected her to search in the wrong location. This finding is problematic for the mainstream consensus that children under 3 years of age lack the conceptual capacity to represent others' representational mental states (Perner, 1995; Saxe, Carey, & Kanwisher, 2004). Building on this finding, we developed a non-verbal version of the false belief task, using eye-tracking technology and measuring anticipatory looking. The results revealed that two-year-old children were able to correctly anticipate an actor's behaviour based on her inferred false belief (Southgate, Senju, & Csibra, 2007).

The aim of the current study was to explore whether children with ASD between 6 to 8 years, who were predicted to have difficulty in standard, verbal false belief task (Happé, 1995), could correctly anticipate the behaviour of an agent with a false belief, like typically developing 2-year-olds (Southgate et al., 2007). This task has a number of advantages over standard false-belief tasks. First, because the task does not impose verbal instructions or questions on the participants, it is free from any confounding factors based on the children's verbal ability (Csibra & Southgate, 2006). Secondly, the non-verbal nature of the current task, along with the measurement of spontaneous eye movements, enabled us to record children's spontaneous response to the scene, rather than measuring an elicited response specific to the task structure. Thirdly, we removed the object from the scene in order to avoid the potentially problematic reality bias (Birch & Bloom, 2003), which may sway children towards responding with the actual location of the object.

One can make at least two different predictions for the outcome of this study. First, if the difficulty of children with ASD on the standard false belief task reflects a difficulty in executive attention or verbal understanding, they may pass this non-verbal version of the false belief task which largely eliminates these problems. On the other hand, if children with ASD do not spontaneously attribute mental states to anticipate other people's behaviour, they should not show anticipatory looking in this task.

Methods

Participants. Data from 12 children with ASD (1 female, 11 male), as well as 17 typically developing children (TD; 8 female, 9 male) were included in the analyses. An additional 8 children (6 ASD, 2 TD) also participated in the study but were excluded from the analyses because of failure to watch the stimulus during recording (3 ASD), technical problems (1 ASD), or not reaching inclusion criteria during familiarization trials (2 ASD, 2 TD, see Procedure for details). Children with ASD included in the final analyses had been diagnosed with Autistic Disorder (6), Asperger Disorder (1), PDD-NOS (1) or Pervasive Developmental Disorder (without a detailed diagnosis, 4) by at least one child psychiatrist or pediatrician. To confirm their clinical manifestation, the Japanese version of the Autism Screening Questionnaire (ASQ-J) (Berument, Rutter, Lord, Pickles, & Bailey, 1999; Dairoku, Senju, Hayashi, Tojo, & Ichikawa, 2004) was administered to all of the children. All the children with ASD scored above the cut-off point (13), and all the TD children scored below the cut-off point. Verbal and non-verbal intelligence was measured with the Japanese version of the Picture Vocabulary Test (PVT) (Ueno, Nadeo, & Iinaga, 1991) and the Japanese version of Raven's Coloured Progressive Matrices (RCPM) (Raven, 1956; Sugishita & Yamazaki, 1993). Children's scores for each test, as well as their chronological ages and scores of ASQ-J, are summarized in Table 1. All the children were recruited from a local school, and written informed consent was obtained from one of the children's guardians before the study. This study has been approved by the Research Ethics Committee of the Graduate School of Arts and Sciences, University of Tokyo.

Table 1. Mean Chronological Age (CA), Verbal Mental Age (VMA), scores of Raven's Coloured Progressive Matrices (RCPM) and scores of Japanese version of Autism Screening Questionnaire (ASQ-J) for children with Autism Spectrum Disorder (ASD) and typically developing children (TD).

	ASD (n = 12)		TD (n = 17)		Group difference
	M (SD)	range	M (SD)	range	
CA	7;9 (1;0)	6;6 – 8;10	7;6 (0;11)	6;5 – 8:10	n.s.
VMA	6;3 (2;5)	3;0 – 12;0	9;4 (2;2)	4;8 – 12;0	**
RCPM	25.1 (6.8)	14 - 35	29.5 (5.1)	20 - 36	n.s.
ASQ-J	22.1 (5.0)	17 - 33	2.7 (3.2)	0 - 11	**

M: average, SD: Standard Deviation, **: $p < .01$, n.s.: not significant.

Eye-Tracking version of the False Belief Test (ET-FB). A Tobii (Stockholm, Sweden) 2150 Eye Tracker, integrated with a 20-inch TFT monitor was used to present the stimuli and record eye movements. Stimulus presentation and recording were controlled via a computer with Tobii's ClearView software. Children were seated approximately 50 cm from the monitor. A five-point calibration was completed before the stimulus presentation (For technical details about the apparatus and the calibration procedure, see (von Hofsten, Dahlström, & Fredricksson, 2005).

The stimuli consisted of four familiarization trials, followed by one of two test trials. All the stimuli, except for the first two familiarization trials, were identical to those used in our previous study (Southgate et al., 2007). The same familiarization trials were presented to all the participants, in the same order, and each participant observed one of two versions of the test trial (FB1 or FB2). The general setup of the scene was the same for all trials: An actor was seated behind a panel containing two windows, and in front of each window there was an opaque box with a lid (Figure 1).

The purpose of the familiarization trials was (1) to show that the actor's goal was to obtain the ball, and (2) to teach the child the contingency between the windows being illuminated and a corresponding 'chime' sound, and the subsequent opening of one of the windows by the actor. Two additional familiarization trials were included at the beginning of the study to maximize the chances that children would learn this contingency by the test trial (see Results). In both of these extra familiarization trials, participants saw a red toy whale sitting on top of the left-hand (trial 1) or right-hand (trial 2) box. Both windows were then illuminated and a chime sounded. After a 1750-ms delay, the actor reached through the window behind the box on which the toy whale sat (Figure 1a). The third familiarization trial started with the actor watching a puppet as it appeared, opened the lid of the left-hand box, placed a brightly coloured ball in the box, closed the lid and disappeared. After the puppet disappeared, the two windows were illuminated and a chime sounded as in the preceding familiarization trials. Again, after a 1750-ms delay, the actor reached through the left-hand window, opened the lid of the left-hand box, reached into it and retrieved the ball (Figure 1b). The fourth familiarization trial was identical to the third familiarization trial except that the puppet put the ball in the right-hand box, the actor reached for the right-hand box and the video stopped at the point when the actor's hand made contact with the lid of the box.

In the FB1 condition (Figure 1c), the puppet appeared at the centre of the stage, deposited the ball in the left-hand box and returned to the centre. The puppet then went back to the left-hand box, opened the lid, took the ball and placed it in the centre. The puppet then opened the lid of the right-hand box, retrieved the ball and put it inside the box, and closed the lid. The puppet then returned to the left-hand box (while the actor's attention followed), closed the lid and disappeared. At this point, the sound of a phone ringing was played and the actor turned around as if she was attending to this sound. As soon as the actor turned away, the puppet reappeared, opened the right-hand box, retrieved the ball, closed the lid and disappeared with the ball. If the participants could represent the actor's false belief, they should be able to deduce that (1) the ball is no longer in the right-hand box, but (2) the actor did not see it disappear, therefore (3) she should have the false belief that the ball is still in the right-hand box. On the basis of this false belief attribution, children should predict that (4) the actor would reach through the right-hand window once the window was illuminated. As soon as the puppet disappeared, the phone stopped ringing and the actor turned back. Then the windows were illuminated and a chime sounded. After that, the actor remained still for the following 5 s.

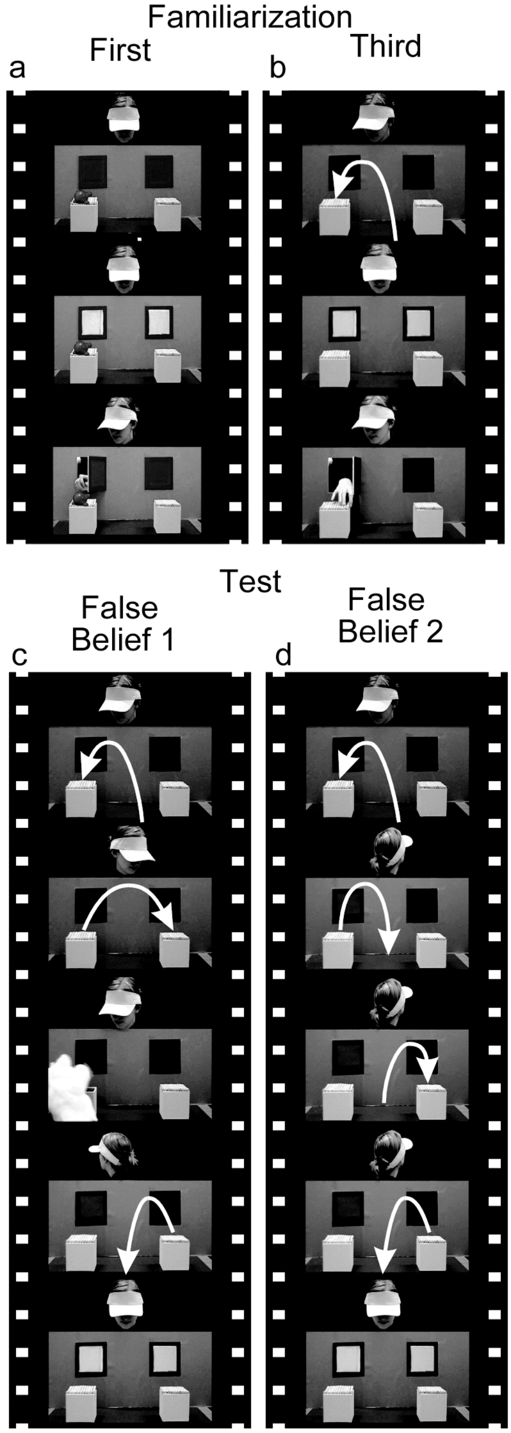

Figure 1. Selected frames of from the events used in the experiment. White arrows indicate the relocation of the object. In the first familiarization trial (a), an object was placed on the left box. In the third familiarization trial (b), a puppet put the object into the left box. The second and the fourth familiarization trials were the same as the first and the third trials respectively, except that the object was placed to the right. In each case, the windows were then illuminated and then the actor reached through the window to the object. In the test trial, the puppet initially put the object in the left box, but the subsequent events differed between the conditions. In one condition (c), the puppet moved the object to the right box and then returned to the left box to close the lid; after the actor turned around, the puppet removed the object from the scene. In the other condition (d), the actor turned around before the puppet moved the object to the centre and then the right-hand box, and then removed the object from the scene. In both conditions, after the puppet removed the object, the actor turned back to the scene and the windows were illuminated.

In the FB2 condition (Figure 1d), the puppet first placed the ball in the left-hand box and disappeared. This was immediately followed by the phone ringing, at which point the actor turned away. Then the puppet reappeared, took the ball out of the left-hand box and closed the lid. The puppet then placed the ball into the right-hand box, closed the lid and went back to the centre. Then the puppet returned to the right-hand box, removed the ball, closed the lid, and disappeared with the ball. If the participants could represent false beliefs, they should predict that the actor would reach through the left-hand window to the box in which the ball was placed as she was watching. As in the FB1 condition, once the puppet disappeared, the phone stopped ringing and the actor turned back. The windows were then illuminated and the chime sounded. After that, the actor remained still for the following 5 s.

Several controls were incorporated to eliminate any cues which might affect participants' looking behaviour. First, the actor wore a visor, which made the actor's eyes invisible and prevented the participants from following, or attempting to follow, the actor's eye gaze. Second, after turning back toward the stage in the test trials, the actor kept her head centered and made no movement, so as not to give any cues as to where she would search. Our previous study confirmed that, when asked, naïve adults were unable to correctly identify the window the actor would open based on the actor's posture and movement after she turned back to the stage (Southgate et al., 2007).

After the stimulus presentation, the experimenter asked the participants the following question: "Which window will the actor open?" to also obtain a verbally elicited measurement of the participants' false belief understanding in this task.

Standard False Belief Test (S-FB). Participants sat in front of a table, on which two boxes (one red and one blue) were set side by side. One of the two experimenters (Experimenter A) was seated next to the participant, and the other experimenter (Experimenter B) sat at the opposite side of the table, facing the participant and Experimenter A. Throughout the testing, Experimenter B manipulated a pair of puppets and a toy object to present 'false-belief' stories to the participant. Experimenter A monitored the participants, asked questions to the participants, and wrote down their verbal responses. To double-check participants' responses, the whole testing session was recorded with a video camera, which was situated behind Experimenter B, facing the participant

The testing consisted of three trials. Different pairs of puppets and a different object were used for each trial. Each trial consisted of five phases: (1) Experimenter B introduced one of the puppets (puppet A) to the participant. Puppet A then put an object into one of the boxes and disappeared underneath the table. (2) Experimenter B introduced the other puppet (puppet B) to the participant. Puppet B then took the object out of the box, put it into the other box, and disappeared. (3) Experimenter A asked the participants three questions to confirm their memory of the events so far. The questions were: "Which box is the [name of the object] in now?", " Who put the object in the box?", and "In which box did [the name of puppet A] put the [name of the object]?". (4) Puppet A appeared on the stage and said "Hello [name of participant]. I'm going to get the [name of object]!". (5) Experimenter A asked the participant a question about the false belief of puppet A, which was: "To which box is [name of puppet A] going to go in order to get the [name of object]?". After the participant's response, Experimenter A praised the participant regardless of their response. Then Experimenter B started the next trial with a different pair of puppets and a different toy object.

Data reduction. Eye-tracking data from the ET-FB was analyzed as follows:

After recording, a gaze replay file showing the exact location of each participant's gaze was exported at 25 frames per second with the ClearView program. From the exported data, the point of fixation was coded frame by frame starting from the point when the windows were illuminated to the end of stimulus presentation. Having obtained the total looking time to each of the two windows, a differential looking score (DLS) was calculated by subtracting the total looking time to the incorrect window from looking to the correct window, and by dividing it by the sum of looking time to correct and incorrect windows. The DLS can range between 1 and -1, being closer to 1 if the participant spent most time looking at the correct location, and closer to zero if the participant looked randomly to both windows. We also coded the direction of first saccade after the illumination of the windows.

Children in the ET-FB task also showed characteristic gaze alternation between the actor and the puppet, which could reflect checking whether the actor is attending to the puppet's actions. Thus, we coded the number of times that this 'gaze checking' occurred, i.e., the number of gaze alternations from the puppet to the actor from the point at which the actor looked away, to the point at which the actor turned back to the scene.

The number of correct responses in the three trials of S-FB were summed and used as the score of false belief understanding on a standard verbal test.

Results

To be included in the analyses, participants were required to understand the contingency between the illumining of the windows (and the chime) and the actor's impending reaching, and had to display anticipatory looking toward the correct window by the fourth familiarization trial. Thus, only participants who looked longer to the correct, than the incorrect, window on this fourth familiarization trial were included in subsequent analyses. Preliminary analyses in the typically developing group found no effects of participants' sex, and so data were pooled over this factor. Scores on the S-FB test were analyzed using an independent samples t-test, and the scores on the ET-FB task were analyzed using a two-way analysis of variance (ANOVA) with group (ASD or TD) and condition (FB1 or FB2) as between-subjects factors.

As predicted, we found a significant group difference on the S-FB task (mean score: 2.35 in TD, and 1.41 in ASD children, $t\,(27) = 2.19$, $p = .038$, *Cohen's d* = 1.14). However, this difference did not remain significant when VMA was covaried out ($F(1, 26) = 1.29$, $p = .27$, $\eta_p^2 = .047$), which suggests that the group difference on the S-FB test in the current sample was mainly due to differences in verbal ability, as was also suggested in a meta-analysis by Happé (1995). Moreover, the group difference was also not significant when the participant's score on the ET-FB task was covaried out ($F(1, 26) = 1.28$, $p = .27$, $\eta_p^2 = .047$). This suggests that the group difference on the S-FB task, at least within the age range of the current participants, can also be explained by the performance on the ET-FB.

In the ET-FB task, children with ASD showed significantly lower DLS than did TD children (Figure 2, main effect of group: $F(1, 25) = 11.10$, $p = .003$, $\eta_p^2 = 0.31$). In contrast to the S-FB task, the group difference in the ET-FB task remained significant when CA, VMA, RCPM, and even the participant's score on the S-FB task were covaried out (all Fs > 8.11, all ps < .009, all η_p^2s > .25). These results indicate that the group differences in DLS in the ET-FB task cannot be explained by the performance on the S-FB task, the children's age, or by their verbal or non-verbal abilities. Follow-up t-tests for the ET-FB task revealed that TD children scored significantly above zero (mean: 0.43, $t(16) = 4.53$, $p < .001$, *Cohen's d* = 1.10) while the DLS in children with ASD did not differ from zero (mean: -0.077, $t(11) = -0.39$, $p = .70$, *Cohen's d* = 0.11). The main effect of condition was also significant in the two-way ANOVA ($F(1, 25) = 5.14$, $p = .032$, $\eta_p^2 = .17$), due to the higher scores in the FB1 than in the FB2 condition. This effect may indicate that, due to the longer duration of the events between the point when the actor looked away and when the she turned back, the FB2 situation demanded more memory than did the FB1 sequence. It is possible that such higher memory load may have impaired children's ability to keep track of the actor's mental states. Note, however, that follow-up t-tests confirmed that TD children scored significantly above zero in both the FB1 ($t(7) = 3.80$, $p = .007$, *Cohen's d* = 1.34) and the FB2 ($t(9) = 2.74$, $p = .035$, *Cohen's d* = 0.91) conditions, but the scores of children with ASD did not differ from zero in either condition (both ts < 1.37, both ps > .30). The interaction between group and condition in the two-way ANOVA was not significant ($F(1, 25) = 0.90$, $p = .35$, $\eta_p^2 = .035$).

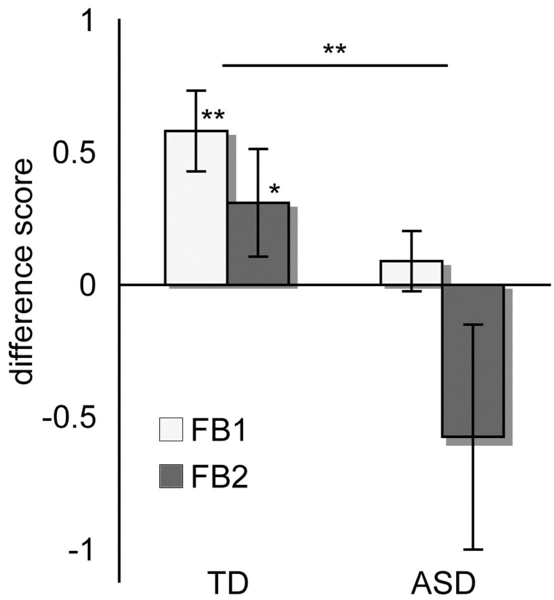

Figure 2. Mean difference scores in action anticipation for each group and each condition. TD: typically developing children, ASD: children with autism spectrum disorder, FB1: false belief scenario 1, FB2: false belief scenario 2, **: $p < .01$, *: $p < .05$, error bar: standard error.

Interestingly, children with ASD showed less gaze checking than did TD children (average frequency: 2.9 times for ASD and 5.3 times for TD, $F(1, 25) = 6.04$, $p = .002$, $\eta_p^2 = .20$). This suggests that children with ASD were less attentive to the actor's head direction than were the TD children, which may plausibly have affected the encoding of the knowledge status of the actor during the task. However, this reduced checking behaviour did not fully account for the group difference in DLS, because this difference remained significant even after the frequency of checking behaviour was covaried out ($F(1, 24) = 9.20$, $p = .006$, $\eta_p^2 = .28$). Note also that the covariant (i.e., the checking frequency) was not significant in this analysis ($F(1, 25) = 0.05$, $p = .82$, η_p^2

= .002). The main effect of condition was also significant in this analysis ($F(1, 25)$ = 5.27, p = .030, η_p^2 = .17), probably because the FB2 condition included a longer period of the actor's looking away than did the FB1 condition. The interaction between group and condition was not significant ($F(1, 25)$ = 0.70, p = .41, η_p^2 = .027).

When we compared the number of children who made their first eye movement after the illumination of the windows towards the correct location, we did not find a significant difference between the groups (p = .39, Fisher's exact test, two-tailed). In fact, the number of children making a correct saccade first (11 children in the TD group and 5 children in the ASD group) was not significantly different from chance in either group. However, it may be more appropriate to assess anticipatory looking towards the correct location at the same delay (1750 ms) after window illumination as the children had experienced during the familiarization trials. Thus, we analyzed participants' fixations between 1.5 s and 2 s after window illumination. Out of 17 TD children included in the analysis, 12 fixated at the correct window, 2 fixated at the incorrect window, 1 made a fixation to both of the windows, and the other 2 looked at the actor's face, making no fixations to either window. Such asymmetric distribution of fixations was significantly different from chance (p = .013, McNemar test). For children with ASD, on the other hand, 4 fixated at the correct window, 4 fixated at the incorrect window, 2 made fixations to both windows, and the other 2 looked only at the actor's face, which was not different from chance (p = 1.0, McNemar test).

Fifteen out of 17 TD children gave the correct answer to the verbal question in the ET-FB task, which was significantly above chance (0.5) (p = .002, binominal test), whereas only 5 out of 12 children with ASD answered correctly, which did not differ from chance (0.5) (p = .77, binominal test). The group difference approached significance (p = .092, Fisher's exact test, two-tailed).

Discussion

As with younger children (Southgate et al., 2007), the use of eye-tracking in the current study demonstrated that older TD children spontaneously anticipate an actor's action based on her inferred false belief: they made longer fixations towards the correct window, particularly at the point when they had learned the actor was likely to open one of the windows and reach for the box. In fact, their score on the ET-FB task correlated significantly with performance on the S-FB task (Spearman's ρ = .54, p = .023), strongly suggesting that, like the S-FB task, our ET-FB task taps the ability to attribute false beliefs. Children with ASD, on the other hand, did not show evidence of such spontaneous anticipatory looking on test trials. As all the children included in the final analyses exhibited correct anticipatory looking behaviour on the final familiarization trial, this failure was unlikely due to a general difficulty or lack of motivation to look in anticipation at locations where something is expected to happen, or to a difficulty in anticipating human actions in general. In addition, as the ET-FB task includes no verbal component and demands minimal executive functioning so that even 24-months-old toddlers can pass the task, it is highly unlikely that the lower performance of children with ASD in the ET-FB task stems from their deviance in verbal development (Happé, 1995) or executive functioning (Russell, Saltmarsh, & Hill, 1999). Moreover, the lack of anticipatory looking in the ASD group cannot be explained by their lower performance on the standard false-belief task alone, because the group difference remained significant even when the scores on the S-FB task were covaried out. The results of the verbal control question corroborates the eye-tracking results by demonstrating that children with ASD, unlike control children, did not anticipate which window would open based on the actor's mental states.

There are several possible reasons why children with ASD fail to show anticipatory looking behaviour in this task. One possibility is that children with ASD are not motivated to monitor others' mental states. Unlike previous studies, our task did not include any instruction but required that children spontaneously monitor others' epistemic mental states in order to be able to anticipate their subsequent behaviour. Thus, it is possible that children with ASD did not exhibit correct anticipatory looking in our study because they lack the social motivation for tracking the actor's knowledge state that would have been a necessary prerequisite for successful performance (Dawson, Webb, & McPartland, 2005). In the current study, children with ASD showed less 'checking' behaviour when the actor was looking away, which suggests that they were less attentive to the actor's potential perceptual state. Note that this account does not entail that children with ASD would never anticipate actions. In fact, all the children included in the final sample correctly and spontaneously predicted the actor's behaviour in the final familiarization trial, suggesting that they did anticipate the person's behaviour based on her goal and the object's location. Ruffman, Garnham and Rideout (2001) also found that children with ASD tend to make less spontaneous anticipatory looking for social stimuli even when no false belief attribution is required. In their study, children were told stories, in which protagonists chose one of two locations based on their desire (i.e., the one where a desired object had been placed) or on social information (i.e., the one that the protagonist's father had told was safe). In this situation, children with ASD tend to show less correct looking than control children, whereas the two groups performed equally in verbal measures. It is thus more likely that the difficulty of action anticipation in children with ASD is limited to situations that require spontaneous monitoring of others' epistemic mental states.

Another possibility is that individuals with ASD have a fundamentally cognitive (and perhaps modular) impairment in Theory of Mind (Leslie, Friedman, & German, 2004). Ozonoff and Miller (1995) demonstrated that explicit and systematic teaching of social-cognitive principles can improve performance on the false belief task in children with ASD, but does not affect their social competence in daily life. They even argued that "*we were more successful in teaching our subject to "hack out" rules and strategies to infer the mental states of others*" (Ozonoff & Miller, 1995, p.429). In addition, Happe (1995) conducted a meta-analysis and found that children with ASD need more than twice (9.2 years) the VMA than TD children (4 years) to pass the standard false belief task. This could also suggest that children with ASD are using verbally mediated compensatory cognitive skills to succeed on false belief tasks. As the current ET-FB task involved no verbal cues or instructions that could have promoted the use of such compensatory strategies, children with ASD, who may have difficulty in attributing epistemic mental states, had no basis for predicting the actor's behaviour. Whichever account proves to be a better explanation, the current results strongly suggest that the impairment in false belief understanding in children with ASD is not simply due to the difficulty in understanding verbal instruction, or in interpreting the meaning of mental state verbs such as *see*, *know* or *think*.

The current results suggest that the difficulty in passing the false belief task in children with ASD cannot be reduced to their delayed or deviant development of verbal skills (Happé, 1995) or executive functions (Russell et al., 1999). By contrast, the reduced spontaneous checking behaviour to the actor's face during the task is consistent with recent literature suggesting atypical social orienting in children with ASD (Kikuchi, Senju, Tojo, Osanai, & Hasegawa, in press; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Osterling, Dawson, & Munson, 2002). It may even suggest that the atypical development of theory of mind in ASD is based on an atypical pattern of social orienting, which is hypothesized to be caused by atypical functioning of subcortical structures such as amygdala, and its communication with cortical structures (e.g. Dawson et al., 2005; Johnson, 2005; Schultz, 2005). This hypothesis is consistent with neurological evidence suggesting the involvement of the amygdala in both theory of mind processing (Fine, Lumsden & Blair, 2001; Stone, Baron-Cohen, Calder, Keane & Young, 2003) and social orienting (Adolphs, Gosselin, Buchanan, Tranel, Schyns, & Damasio, 2005; Spezio, Huang, Castelli, & Adolphs, 2007). However, further studies will be required to examine the relations between spontaneous checking behaviour and correct anticipation based on mental states, as the current study did not find a significant correlation between these measures and the difference in the frequency of face gaze did not account for the group differences in correct anticipation.

A number of limitations in the current study make us cautious to generalize the current results beyond the range of the age and verbal/nonverbal skills of the children with ASD who participated in the current study. Firstly, due to the small sample size and the lack of quantitative measurements of autistic symptoms such as ADI or ADOS, it is difficult to clarify whether the performance in the current task relates to the degree of autistic symptoms or the difference between the subgroups (i.e. Autism, Asperger Disorder and PDD-NOS). Although this does not lessen the main result that children with ASD, as a group, did not demonstrate the correct anticipatory looking based on the actor's false belief, further studies will be beneficial to explore the possible differences in the theory-of-mind skills within the 'autism spectrum'.

Secondly, because the participants with ASD in the current study also showed lower performance on the standard false belief task, possibly due to lower verbal MA, we cannot rule out the possibility that non-specific developmental characteristics, such as verbal MA, have affected the current results. Note that this does not mean that the current results can be explained by the higher verbal MA in the control group than the ASD group, mainly because our previous study has demonstrated that even 25-months-old typically developing toddlers show correct anticipatory looking (Southgate et al., 2007). In addition, the group difference in ET-FB task remained significant when the VMA is covaried out. Moreover, another recent study has revealed that even adults with ASD, who easily pass standard FB tasks, still fail to show spontaneous anticipatory looking based on an actor's false belief (Senju, Southgate, White & Frith, 2009), suggesting that high verbal MA does not necessarily result in successful spontaneous false belief attribution in ASD. Further studies will be beneficial with multiple control groups matched with chronological, verbal and nonverbal mental ages, as such matching has the potential to reveal further details of the cognitive profile of ASD (e.g. Burack et al., 2002; Russo et al., 2007). In addition, even though we did not find any effect of participants' gender in the current study, further studies with larger sample sizes would be necessary for exploring gender differences which do not always have large effect sizes.

To conclude, the current study demonstrates that children with ASD, at least in the age range included in the current study, fail to spontaneously anticipate others' actions when such anticipation requires the attribution of a false belief to the actor. Thus, these results suggest an impairment in mentalizing skills in these children that is independent of their verbal abilities. The development of nonverbal tasks has opened up new opportunities to examine the early development of theory of mind not only in typical development, but also, as demonstrated here, in atypical development such as ASD. Further research is needed to explore whether one can detect the impairment in theory of mind in much younger children with ASD and whether such early impairments predict later manifestation of autistic symptoms. In addition, the positive correlation between the performance on our nonverbal tasks and the traditional false belief task opens up a real possibility for use with patients with language difficulties as well as pre-verbal children. The current results have demonstrated that the ET-FB task can be applied to school-aged children as well as toddlers, which make it a feasible tool for assessing the developmental trajectory of the capacity to encode false belief from early childhood to adulthood (Senju et al., 2009).

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