Do autistic adults spontaneously reason about belief? A detailed exploration of alternative explanations

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Research

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Do autistic adults spontaneously reason about belief? A detailed exploration of alternative explanations

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Abstract

Background: Some autistic individuals with good compensatory skills may circumvent diagnosis, but still struggle with mentalizing. This missed or delayed identification can deprive them of the opportunity to receive necessary support and interventions. Thus, more sensitive assessment techniques are needed that are not susceptible to compensation. One such promising assessment, Southgate et al. (2007)'s anticipatory looking paradigm, has presented exciting yet inconclusive evidence surrounding spontaneous mentalizing in autism. The present study therefore aimed to advance this paradigm by addressing some alternative explanations and scrutinizing the claims that have been made in the literature, through implementing a multi-trial design with shorter trials, matched true-belief conditions, and both high and low inhibitory demand false-belief conditions. We also sought to inspect if any group differences were related to group-specific patterns of attention on key events.

Methods: Seventeen autistic adults were compared with nineteen neurotypical adults on an adapted implicit mentalizing task and a well-established explicit mentalizing task. One-sample *t*-tests were used to compare performance to chance on the implicit task, a mixed-design ANOVA was conducted to examine main effects of group, time and belief and their interactions, and *t*-tests were used to further explore gaze patterns.

Results: The two groups were comparable in the explicit mentalizing task, indicating sophisticated mentalistic reasoning; however, the autism group did not show anticipatory looking behaviour in the implicit mentalizing task, indicating that they struggled to mentalize the protagonist's beliefs. Surprisingly, there was no group difference in attention distribution during any of the key event.

Limitations: Our true-belief conditions may also trigger mentalizing; future studies should therefore create a mentalizing-free baseline matched with the false-belief scenario.

Conclusions: Our findings further document that although many autistic individuals perform well in explicit tasks, they struggle to spontaneously mentalize in implicit tasks, consistent with their everyday social difficulties. We ruled out some alternative theoretical explanations for this pattern of performance, leading to a better understanding of mentalizing difficulties. We also presented evidence that autistic adults may process information from social cues in the same way as neurotypical adults, but this information is not then used to update mental representations.

***Keywords*: ** Autism, spontaneous mentalizing, theory of mind, implicit, anticipatory-looking, eye-tracking, false-belief

Background

The recognition of an individual as autistic is dependent on diagnostic criteria and associated diagnostic assessments and practices. Autism has always been identified on the basis of behaviour despite a longstanding acceptance that it has a strong genetic component [1]. The diagnosis of autism therefore currently relies on clinicians' subjective interpretation of behaviours through observation and/or parental report. This has resulted in some autistic individuals not receiving a timely diagnosis and presumably others not being identified at all; indeed, under this diagnostic framework, adult diagnosis is increasingly common [2-5], individuals with high IQ are diagnosed later than those with lower IQs [6-8], and females on average receive their diagnosis considerably later than males and are more likely to have been previously misdiagnosed [3, 9-12]. One reason why this is problematic is that those individuals who receive a diagnosis are likely to be least able to compensate, or to have particular characteristics that cannot easily be camouflaged [1, 13-15]. However, this does not necessarily mean that the neurodevelopmental difficulties of those who are good compensators and can circumvent diagnosis have genuinely remitted at a cognitive and neural level; rather, these difficulties persist and such behavioural compensation comes at a great cost [1, 13, 16, 17]. It is therefore critical to develop more sensitive assessment techniques that are not susceptible to compensation and that target underlying cognitive ability [18].

Implicit mentalizing tasks hold promise as one such assessment. Southgate, Senju [19]'s anticipatory looking paradigm has been suggested to be able to detect more subtle false-belief (FB) reasoning than traditional explicit, and even than some other implicit, mentalizing paradigms [19, 20]. Senju, Southgate [21] provided the first evidence for a dissociation between implicit and explicit mentalizing task performance; autistic adults' looking behaviour was not biased by the protagonist's FB, indicating that they were not spontaneously mentalizing, despite performing comparably to their neurotypical counterparts on explicit mentalizing tasks. Presumably, in the latter instance, autistic adults may ‘hack’ the solution through compensatory strategies, such as linguistic abilities, executive functions or declarative memory [e.g. 1, 13, 22, 23-26]. These results have been replicated with both autistic children [e.g. 27] and with autistic adults with an alternative version of the task [e.g. 28].

Yet, this promising finding has been challenged, both in terms of the reliability of the paradigm and the interpretation of the data [e.g. 29, 30, 31].

Challenges to implicit mentalizing tasks in autism research

In Southgate, Senju [19] and Senju, Southgate [21], each participant was only presented with one test trial. This single-trial design is problematic; trial-by-trial variation is particularly large between participants, which tends to dramatically escalate error variance, as well as dropout rate, for example, 44% in Southgate, Senju [19], although only 3% in Senju, Southgate [21], and therefore attenuate reliability [29, 32]. A multi-trial design would improve the signal-to-noise ratio and increase power, which would allow for a better estimation of individual performance. Therefore, in the present study, we set out to increase the number of trials to improve the reliability of the task.

Second, both studies only presented a FB condition; no matched true-belief (TB) condition, in which the viewer’s belief should be consistent with that of the protagonist, was included as a baseline for viewing behaviour. This lack of control condition opens the door to alternative explanations of the results. Heyes [31] proposed that neurotypical individuals pass this task due to submentalizing (domain-general attentional) processes rather than relying on dedicated mentalizing processes. Specifically, she claimed that neurotypical individuals exhibit correct anticipatory looking in FB reasoning trials because they get distracted by the protagonist conspicuously turning her head away, and therefore do not pay attention to, or remember, the subsequent object displacement. Heyes [31] therefore argued that neurotypical individuals predict the forthcoming action of the protagonist based on their own FB of the object's location rather than the protagonist's FB about it. On the other hand, she suggested that autistic individuals are less distracted by the protagonist and hence know the object is not in either of the two boxes, but are also less likely to predict the protagonist's subsequent action. Alternatively, it has been proposed that autistic individuals are less able to inhibit their own belief, which here equates with reality, and thus predict the protagonist's action on this basis [TB/reality bias; 33].

Accordingly, poor performance on the commonly reported outcome measures of this task alone cannot be used to conclusively deduce that autistic individuals have difficulties in spontaneous mentalizing. This study aims to address these alternative explanations through both including TB conditions that closely match with our FB conditions and providing a detailed analysis of eye-movements throughout the paradigm. If Heyes [31]'s submentalizing hypothesis is correct, that neurotypical individuals are indeed distracted by the head-turn, we should see differences between the participant groups in visual attention to the key events. Specifically, during this period neurotypical individuals would attend and therefore fixate more on the protagonist but less on the puppet moving the object than autistic individuals. However, both groups should pay attention to the object displacement in a TB condition where the protagonist also watches the movement of the object. In addition, if a TB/reality bias prevented autistic individuals from passing the FB condition, then they should consistently look at the current location of the object in the FB condition.

Overcoming these challenges

Several subsequent studies have already endeavoured to improve the reliability of the Southgate, Senju [19] paradigm by introducing TB conditions and/or a multi-trial design. For example, using the same task as Senju, Southgate [21], Gliga, Senju [34] considered one of the familiarization trials as a TB condition, and concluded that siblings of autistic children were able to attribute TB, but not FB, to others and thus anticipate their actions. However, this familiarization trial was not well-matched with the FB condition, being shorter and simpler, and not involving a head turn. A TB condition comparable to the FB condition is needed to verify whether autistic individuals struggle specifically with spontaneously mentalizing.

Likewise, the empirical results from studies adopting a multi-trial design are, to date, mixed and unclear [35, 36]. Schneider, Bayliss [37] were the first to investigate how spontaneous mentalizing operates over time in neurotypical adults by embedding a multi-trial design and a matched TB condition into their anticipatory looking paradigm, and claimed that spontaneous mentalizing can be sustained over the course of a multi-trial procedure. Using the same paradigm in autistic adults, Schneider, Slaughter [28] replicated the observations of Senju, Southgate [21]; autistic individuals did not spontaneously engage in mental state reasoning across the test trials, despite performing well in explicit mentalizing tasks, indicating that multi-trial designs are viable and are not susceptible to compensatory learning in autistic individuals.

However, it is important to note that Schneider, Bayliss [37] and Schneider, Slaughter [28] did not analyse whether participants showed a clear looking bias towards the belief-congruent box within each trial type. Instead, they compared the looking bias towards the belief-congruent box on FB trials and the belief-incongruent box on TB trials. Thus, it is unclear whether the belief manipulation within each condition was successful; indeed, both autistic and neurotypical participants appeared to spend a similar amount of time looking at both boxes in the TB condition [28, Fig. 2 & Fig. 3].

Additionally, Schneider's studies consisted of 10 FB and 10 TB trials, each more than one minute in duration, plus at least 20 familiarization trials, amplifying the total duration of the task. In the present study, we therefore chose to make the paradigm more streamlined by removing any unnecessary actions and potential social confounds (an extra object displacement in the original FB trials and the protagonist's wave and smile), and keeping familiarization trials to a minimum.

Another factor worth highlighting in Schneider, Slaughter [28] is that, during the anticipatory period, both groups allocated their first fixation to the protagonist's face in more than seven of the ten trials in each condition. This meant that in each condition, only a maximum of three test trials from each group were included in the analysis. One possible reason for losing more than 70% of the data could be the absence of an occluder between the protagonist and the scene, a disparity between this paradigm and that of Southgate, Senju [19]. It is possible that by removing the occluder, rather than making anticipatory saccades to the belief-congruent area as the first place where movement was expected, participants looked to the protagonist in anticipation of her movement. A second reason may be that the protagonist left the room, rather than turning to the back as in Southgate, Senju [19]. This meant that the participant could not be sure of the protagonist's knowledge of the object's location – whilst off scene, it is unclear what the protagonist was able to see. A further contention is whether the reappearance of the protagonist is a salient event, which could result in retroactive memory interference on object displacement during the protagonist's absence [31]. Moreover, it is worth noting that in Schneider, Slaughter [28] the object was displaced twice in the TB scenario but only once in the FB scenario before the protagonist came back (in Southgate, Senju [19], the object was displaced twice in all trials). Therefore, the higher memory load required in the TB condition may have caused the non-significant looking difference between the belief-congruent area in TB trials and the belief-incongruent area in FB trials. In order to avoid these potential caveats and by doing so increase the number of trials included in the analysis, we chose to retain the occluder, to keep the protagonist visible at all times, and to displace the object only once in each condition in this study.

Furthermore, both Schneider, Bayliss [37] and Schneider, Slaughter [28] used a FB condition with high inhibitory demands, as the object was displaced to the other box while the protagonist left the room, rather than removing the object from the scene (i.e. low-demand) as in Southgate, Senju [19]. Wang and Leslie [33] directly contrasted high- and low-demand FB conditions by editing the videos from Southgate, Senju [19]. They found that both neurotypical toddlers and adults showed clear anticipatory looking behaviours towards the belief-congruent area in the low-demand condition, but no looking bias in the high-demand condition. As a result, they suggested that the high-demand scenario requires greater cognitive resources to inhibit one's own belief about the object's location, undermining the performance of FB-based anticipatory looking tasks in the neurotypical population. Accordingly, we chose to look at the effectiveness of belief manipulation in our paradigm, and compare high- and low-demand FB conditions in both autistic and neurotypical individuals.

Schuwerk, Vuori [38] also reported a multi-trial study, this time across just two trials, suggesting that experience might improve autistic individuals' performance when the outcome action (i.e. the protagonist opening the belief-congruent window and retrieving the object) is shown. Autism and neurotypical groups differed in looking bias in the first FB trial, consistent with Senju, Southgate [21], but not in the second test trial. However, only the second trial tested the learning effect, and the looking bias of the autism group did not differ from chance in either test trial, so whether the result was due to the potential modulatory effect of learning or error variance, and whether its magnitude was truly substantial in autism, remain to be investigated. Indeed, this same improvement was not seen in autistic children [39]. Moreover, any improvement in performance by the autism group could have been due to compensatory learning of a behavioural contingency (e.g. the protagonist would open the window above the incorrect box) during the first trial, without representing the protagonists mental state [35]. For these reasons, in this study we chose not to show the outcome action in experimental trials. If the improved performance observed in Schuwerk, Vuori [38] was due to an increase in mentalizing, then the performance of autistic individuals in our task should also increase over time to the level of neurotypical individuals. On the other hand, in line with Schneider, Slaughter [28], we might expect to see no change in performance over time in either participant group.

To summarise, the existing adaptations to the original anticipatory looking paradigm have presented exciting, yet inconclusive, evidence surrounding spontaneous mentalizing in autism. The present study therefore sought to advance the Southgate, Senju [19] paradigm by implementing a multi-trial experiment with shorter trials, matched TB conditions, and both high and low inhibitory demand FB conditions to scrutinize the claims that have been made in the literature. On the basis of the mentalizing theory of autism, we predicted that both autism and neurotypical groups would look significantly longer at the belief-congruent than the belief-incongruent area in the TB conditions but would show no looking bias in the high-demand FB condition. In the low-demand FB condition, we predicted that autistic individuals would show no looking bias, whilst neurotypical individuals would be able to anticipate the protagonist's FB-based action. Additionally, following Gliga, Senju [34], we expected both autism and neurotypical groups to show belief-congruent performance in the familiarization trials.

Methods

Participants

Participants were recruited through a participant database at the Institute of Cognitive Neuroscience, autism support groups in and around London, and advertisements placed around the local community. This study was approved by the UCL Research Ethics Committee, and written informed consent was obtained from all participants. Initially, 19 autistic and 21 neurotypical adults took part but four participants (two autistic and two neurotypical) were excluded from the analysis due to poor data quality (see ***Data Processing*** below). The resulting two groups were comparable for age ($t(34) = 1.20$, $p = .239$, $d = 0.40$), sex ($\chi^2(1) = 0.34$, $p = .559$, odds ratio = 1.53), Verbal IQ ($t(34) = 0.23$, $p = .819$, $d = 0.08$), Performance IQ ($t(34) = 0.22$, $p = .829$, $d = 0.07$) and Full-scale IQ ($t(34) = 0.09$, $p = .928$, $d = 0.03$), as measured by the Wechsler Abbreviated Scale of Intelligence, Second Edition [WASI-II; 40], and all participants had a Full-scale IQ greater than 80 (see Table 1). None of the neurotypical participants reported a diagnosis, or family history, of psychiatric or neurodevelopmental disorders. Each participant in the autism group had previously received a diagnosis of autism spectrum disorder, Asperger syndrome, high functioning autism or atypical autism from a qualified clinician. The Autism Diagnostic Observation Schedule Second Edition [ADOS-2; 41] was used to verify participants' autism diagnosis. ADOS scores were available for nine autistic participants (see Table 1); and seven of those met the criteria for autism or autism spectrum classification. The two participants who scored below the threshold, and the eight who had no ADOS score, were retained within the sample because scores below the cut-off are not uncommon in highly intelligent adults [42].

[Insert Table 1]

Procedure

Participants started the session by completing the WASI-II, then Section A of the implicit mentalizing task, followed by the explicit mentalizing task, and finished with Section

B of the implicit mentalizing task. Participants were then fully debriefed. The overall duration of the experiment was 1.5 hours.

Explicit mentalizing task

The Mental State set from the Strange Stories Task [43, 44], an advanced mentalizing test, was used to assess participants' ability to infer mental states in social situations explicitly. In addition to accuracy (maximum score of 16), comprehension time was recorded (time elapsed from the start of reading a story to the start of answering the question).

Implicit mentalizing task

The implicit mentalizing task used a multi-trial anticipatory looking paradigm with matched true-belief (TB) and false-belief (FB) conditions, which was adapted from the anticipatory looking paradigm in Southgate, Senju [19]. In an attempt to maintain participants' attention, the task was split into two sections (A and B) with a 20-minute interval in between (see Figure 1). Participants were instructed to passively view some videos and informed they would be asked questions about their content at the end, to encourage them to pay attention and watch carefully. The questions asked about basic features of the videos (e.g. the colour of the puppet) and participants' judgements (e.g. the most frequent final location of the object), but participants were not informed of the style of question in advance to avoid directing their attention to particular features of the videos.

[Insert Figure 1]

Section A contained one familiarization block, and both Sections A and B contained two experimental blocks (see Figure 1). The familiarization block included four short and four long familiarization trials, which enabled participants to learn the contingency that the protagonist would retrieve the object after an alert signal (the windows illuminated and a chime sounded simultaneously for 800ms). The short familiarization trial started with the object on top of one of two boxes (see Figure 2b). The scene was frozen for 2,800ms from the onset of the alert signal. The protagonist then reached through the corresponding window and retrieved the object. On the long familiarization trial, a puppet placed the object into one of the boxes while the protagonist was watching (see Figure 2d). After the puppet left the scene, the alert signal occurred and the scene froze, and then the protagonist reached through the window, opened the box and retrieved the object. To make the contingency between the alert signal and the protagonist reaching through the window more salient, we also filmed two short and two long familiarization trials using transparent boxes to give participants direct perception of the object location (see Figures 2a & 2c). The end location of the object was counterbalanced in the short and long, transparent and opaque trials, producing eight possible videos, which were all displayed in the familiarization block in a random order.

[Insert Figure 2]

Each experimental block started with one short and one long familiarization trial, randomly selected from the eight videos without replacement, to remind participants of the contingency. This was followed by four TB and four FB trials, consisting of two TB and two FB conditions: a. TB short-turn (TBST); b. TB long-turn (TBLT); c. FB high-demand (FBHD); d. FB low-demand (FBLD). Conditions TBST and TBLT were matched to conditions FBHD and FBLD, respectively. In the TB conditions, the protagonist's belief about the object location was congruent with its actual location, while these two locations were incongruent in the FB conditions so that the protagonist held a FB about the object's location. These conditions only used the opaque boxes and the protagonist did not retrieve the object; instead the scene remained frozen for the full 4,800ms from the onset of the alert signal (see Figure 3).

In the TBST condition (see Figure 3a), the puppet placed the object into one of the boxes. A doorbell then rang and the protagonist turned away from the scene, followed almost immediately by the sound of a door closing, whereupon the protagonist turned back to the scene and witnessed the puppet move the object to the other box. Once the puppet had disappeared, the alert signal occurred and the scene froze. In the TBLT condition (see Figure 3b), the only difference was that the puppet returned the object to the original box whilst the protagonist was turned away from the scene and the protagonist did not turn back until the puppet had disappeared, at which point the alert signal occurred. The FBHD condition (see Figure 3c) only differed from the TBST condition in that the protagonist remained turned to the back whilst the puppet moved the object to the other box. The FBLD condition (see Figure 3d) was similar to the TBLT condition except the puppet removed the object from the scene whilst the protagonist was turned away. Each sound was paired with the same corresponding event in all of the experimental videos, and the protagonist's head movements always followed the puppet's movement when she was facing the front to indicate that she was paying attention to the situation.

The box that first contained the object and the direction in which the protagonist turned were both counterbalanced, producing four possible videos for each condition. In each experimental block, two videos were randomly selected from each condition, giving a total of eight videos presented in random order. Participants watched each experimental video once in each section. Mathematica (Wolfram Research, Inc. Version 11.1) was used to code the random presentation sequences of the videos, which were then imported into the presentation software.

[Insert Figure 3]

Apparatus.

A remote screen-based Tobii (Stockholm, Sweden) Pro X3-120 eye-tracker system, with a sampling rate at 120Hz, was used to record gaze data. Visual and auditory stimuli were presented via a Dell Precision 5520 laptop (15.6-inch) with Tobii Pro Studio 3.4.8 software, integrated with the eye-tracker. Participants sat approximately 70cm from the eye-tracker and were instructed to sit still throughout the eye-tracking assessment. A nine-point calibration was performed before each section began.

Areas of interest (AOIs).

Nine AOIs within five timeframes were identified across each trial (see Table 2 & Figure 4). The total fixation duration (TFD) was encoded and extracted through Tobii Pro Studio, measuring the sum of the duration of all fixations within each AOI. According to the scenarios, timeframes 1 and 3 captured object displacement, timeframes 2 and 4 captured the protagonist's head-turn, and timeframe 5 (af) captured action anticipation after the onset of the alert signal. Therefore, to investigate group differences in attention distribution, the TFD of ***Head_1*** and ***Head_3*** were combined as ***Head_bf***, ***Puppet_1*** and ***Puppet_ 3*** were combined as ***Puppet_bf***, ***HeadTurn_2*** and ***HeadTurn_4*** were combined as ***HeadTurn***, and that of ***Belief-congruent_5*** and ***Belief-incongruent_5*** were combined as ***Anticipation_af***. For the long familiarization trials using opaque boxes, the TFD of ***Belief-congruent*** and ***Belief-incongruent*** for two different timeframes were extracted (see Table 2). For timeframe 5, 4,800ms AOIs were used to evaluate if participants learned the contingency of the task on experimental trials, while 2,500ms AOIs were used in familiarization trials.

[Insert Table 2 & Figure 4]

Data processing.

Differential looking scores (DLS), which measure participants' looking preference between two visual targets, were calculated by dividing the difference between the total looking time to the ***Belief-congruent*** and ***Belief-incongruent*** AOIs, by the sum of the two. DLS ranged from 1 to -1, closer to 1 if participants showed a looking bias towards the ***Belief-congruent*** AOI, closer to -1 if they were biased towards the ***Belief-incongruent*** AOI, and closer to 0 if they looked equally to both AOIs, equivalent to chance performance.

Three exclusion criteria were applied to ensure participants were paying attention to the key events in the videos (e.g. watching the hand retrieve the object). First, the data from the entire task were excluded for any participant whose average DLS in the familiarization block (based on the full 4,800ms post-flash) was missing or below chance, to confirm that they had paid attention to the key event (a combination to the prediction and the action itself). Second, the data from each experimental block were excluded if the average DLS of the two familiarization trials at the beginning of that block was missing or below chance. Third, participants were excluded if they missed more than 25% of data. After data cleaning, two participants were excluded in each group. On average, 88.16% of data points remained in TBST, 86.84% in TBLT, 84.54% in FBHD and 85.86% in FBLD. Therefore, each condition had roughly seven effective trials from each participant.

Results

Explicit mentalizing task

Independent samples *t*-tests revealed that performance on the Strange Stories Task was comparable between groups, both in terms of accuracy (autism: $M = 13.29$, $SD = 2.17$; neurotypical: $M = 13.68$, $SD = 2.29$; $t(34) = 0.52$, $p = .604$, $d = 0.18$) and comprehension time (autism: $M = 29.40$, $SD = 9.64$; neurotypical: $M = 29.02$, $SD = 6.84$; $t(31) = 0.13$, $p = .895$, $d = 0.05$).

Implicit mentalizing task

Differential looking scores (DLS).

One-sample *t*-tests, comparing the average DLS of all 4 of the long familiarization trials with opaque boxes (based on the first 2,500ms post-flash, before the protagonist reached through the window) to chance performance, were conducted in each group separately to assess action prediction. Both groups performed significantly above chance (autism: *M* = 0.33, *SD* = 0.38, *t*(16) = 3.59, *p* = .002, *d* = 0.87; neurotypical: *M* = 0.19, *SD* = 0.38, *t*(18) = 2.19, *p* = .042, *d* = 0.50) but no difference was found between the groups (*t*(34) = -1.10, *p* = .279, *d* = 0.37), indicating that both groups were able to correctly predict the protagonist's actions.

The same tests were conducted for each experimental condition in the neurotypical group to check the validity of the implicit mentalizing task. The DLSs for TBST (*M* = 0.24, *SD* = 0.43, *t*(18) = 2.45, *p* = .025, *d* = 0.56), TBLT (*M* = 0.39, *SD* = 0.34, *t*(18) = 4.95, *p* < .001, *d* = 1.14) and FBLD (*M* = 0.21, *SD* = 0.33, *t*(18) = 2.82, *p* = .011, *d* = 0.65) were significantly above chance, but that of FBHD (*M* = -0.06, *SD* = 0.30, *t*(18) = 0.93, *p* = .365, *d* = 0.21) did not significantly differ from 0. This indicated that neurotypical participants showed a preference for the ***Belief-congruent*** location in conditions TBST, TBLT and FBLD, but did not show any looking bias in condition FBHD.

The results in the autism group revealed that the DLS was not significantly above 0 in any condition: TBST (*M* = 0.11, *SD* = 0.40, *t*(16) = 1.15, *p* = .268, *d* = 0.28), TBLT (*M* = 0.09, *SD* = 0.30, *t*(16) = 1.27, *p* = .224, *d* = 0.31), FBLD (*M* = 0.04, *SD* = 0.38, *t*(16) = 0.39, *p* = .698, *d* = 0.10), FBHD (*M* = 0.06, *SD* = 0.26, *t*(16) = 0.92, *p* = .373, *d* = 0.22). Since condition FBHD did not produce performance above chance in either group, we decided to focus the following analysis on the FBLD condition and its control condition, TBLT.

A 4x2x2 mixed-design analysis of variance was conducted using the DLS as the outcome variable, with Time (Block 1 vs. Block 2 vs. Block 3 vs. Block 4) and Belief (TBLT vs. FBLD) as within-subject factors, and Group (neurotypical vs. autism) as a between-subject factor. Missing values (*n* = 9, less than 25% missing data on the TBLT and FBLD trials for seven participants) were imputed using the group average scores of the corresponding trials. There was a significant main effect of group ($F(1, 34) = 5.25$, $p = .028$, *partial* $\eta^2 = .134$) with the neurotypical group displaying higher DLSs than the autism group (see Figure 5). As shown in Figure 6, neurotypical participants on average gazed almost exclusively within the ***Belief-congruent*** area (i.e. above the dashed line) in both TBLT and FBLD conditions, while autistic participants on average spent time gazing within not only the ***Belief-congruent*** area but also the ***Belief-incongruent*** area (i.e. below the dashed line). Although the means indicate that higher DLSs occurred in the TBLT than FBLD task, the main effect of Belief was not significant ($F(1, 34) = 3.47$, $p = .071$, *partial* $\eta^2 = .093$; see Figure 5). There was also a significant Time*Group interaction ($F(3, 102) = 3.01$, $p = .034$, *partial* $\eta^2 = .081$; see Figure 5). Post-hoc tests (with α-level adjusted to $p = .010$) indicated that the performance of the neurotypical group was significantly higher than that of the autism group in Block 1 ($t(34) = 3.52$, $p = .001$, $d = 1.18$), but not in Block 2 ($t(34) = 1.25$, $p = .219$, $d = 0.42$), Block 3 ($t(34) = 0.17$, $p = .865$, $d = 0.06$) or Block 4 ($t(34) = 1.75$, $p = .090$, $d = 0.59$). This seemed to be mostly due to a reduction in the performance of the neurotypical group over time ($F(3,54) = 2.72$, $p = .053$, *partial* $\eta^2 = .131$). No other interactions were significant.

[Insert Figures 5 & 6]

Fixation Pattern.

We explored group differences in fixation pattern on the TFD at critical time points. Given the critical frames were identical in all TBLT and FBLD trials and we found no interaction between group and belief, the data were collapsed across these two conditions. No group difference was found in ***Head_bf*** ($t(34) = 0.40$, $p = .692$, $d = 0.13$), ***Puppet_bf*** ($t(34) = 1.25$, $p = .220$, $d = 0.42$) or ***HeadTurn*** ($t(34) = 0.90$, $p = .374$, $d = 0.30$; see Figure 7). More specifically, participants looked significantly longer at ***Puppet_3*** ($M = 7.28$, $SD = 1.70$) than ***Head_3*** ($M = 0.69$, $SD = 0.50$) whilst the protagonist was turned away ($t(35) = -22.55$, $p < .001$, $d = 3.76$), and this result held within each group (autism: $p < .001$; neurotypical: $p < .001$). Indeed, as shown in Figure 8, the gaze patterns of both groups were almost identical in timeframes 1, 2, 3 and 4. From Figure 8, neurotypical participants seem on average to spend most of timeframe 5 gazing at the belief congruent and incongruent areas (i.e. below the dashed line, indicating the top of the occluder), whereas autistic participants seem more likely to spend the early part of timeframe 5 gazing at the head (i.e. above the dashed line) before shifting to look at the boxes/windows below. However, there was no group difference in ***Head_af*** ($t(34) = 0.48$, $p = .635$, $d = 0.16$), and only a marginal trend in ***Anticipation_af*** ($t(34) = 1.88$, $p = .063$, $d = 0.63$). Altogether, these analyses indicated that the looking pattern of the two groups did not significantly differ during the key events.

[Insert Figures 7 & 8]

Discussion

The present study aimed to probe spontaneous mentalizing in autism. To overcome the methodological difficulties seen in previous work, a multi-trial paradigm with well-matched true-belief (TB) control conditions was used. We conducted a detailed analysis of gaze patterns throughout individual trials, as well as changes in performance over the test session. Our results support the presence of spontaneous mentalizing difficulties in autistic adults, despite typical allocation of attentional resources to complex social stimuli.

In line with Senju, Southgate [21], we found a dissociation between explicit and implicit mental state reasoning tasks in the autism group. Specifically, in our explicit mentalizing task, which is considered an advanced test of mentalizing [44], the performance of our autistic adults was indistinguishable from our neurotypical group, indicating sophisticated mentalistic reasoning. On the other hand, in the false-belief condition (FBLD) of our implicit mentalizing task, while the neurotypical group showed a bias to look at the belief congruent target location, the autism group split their time equally between the belief congruent and incongruent target locations, indicating that they failed to appreciate the protagonist's false-belief (FB). Of note, these difficulties could not be accounted for by submentalizing processes, attentional differences or difficulties predicting actions (discussed in more detail below). These findings are consistent with the idea that some autistic individuals with a high IQ may acquire the capacity to explicitly 'mentalize' about complex mental states [22], but still struggle to implicitly attribute simple mental states [21].

While our FB results corroborate previous findings, the results of our TB condition were unexpected. Although the neurotypical group displayed a clear looking bias towards the belief-congruent area in both TB conditions, the autism group showed no such bias. This was a surprising finding and deserves detailed consideration as it has distinct implications for the specificity of the mentalizing differences thought to lie at the very core of autism.

Possibilities that can be immediately dismissed are that these results can be explained by a manifestation of submentalizing, attentional differences or a reality/own-belief/true-belief bias. Consistent with Gliga, Senju [34]'s analysis, all of our participants spent the majority of their time looking at the puppet rather than the protagonist's head whilst the object was displaced in both FB and TB conditions. Thus, it is unlikely that the neurotypical adults were distracted by the first head-turn and therefore failed to notice the critical events (i.e. the object displacement) thereafter, as predicted by the submentalizing hypothesis [31]. Similarly, during the action anticipation period, the two groups spent a similar amount of time looking at the protagonist and at the object (i.e. windows and boxes), revealing that autistic individuals have neither paid more attention to non-social stimuli nor less attention to social stimuli than neurotypical individuals, contrary to social attentional theories of autism [e.g. 45]. Likewise, our autistic participants did not show a tendency to fixate on the hidden object location at the end of the videos (in conditions when it remained on the scene). This indicates that a reality/own-belief/true-belief bias is not preventing them from passing the task.

There are two other potential explanations for the chance-level performance of the autism group in the TB conditions. One is that autistic individuals may struggle to spontaneously predict others' actions per se, regardless of mentalizing requirements [46], leading to a lack of preference for the belief congruent location. Importantly, however, we found that both groups of participants showed anticipatory eye-movements predicting the protagonist's hand reach to retrieve the object in the long familiarisation trials (using opaque boxes, based on the first 2,500ms after the onset of the alert signal before the protagonist reached through a window), implying that they were capable of action prediction in its most basic form.

The final alternative explanation we are left with is that our TB conditions also recruited mentalizing to a degree, which makes them difficult for autistic individuals. Although the beliefs of the protagonist and the viewer are congruent in the TB conditions, this is not to say that they are *belief-free* conditions, in which mentalizing would not be elicited. Indeed, a recent fMRI study of spontaneous mentalizing in neurotypical individuals lends support to the role of mentalizing in TB conditions [47]. A set of brain regions, known as the mentalizing network, has been documented to play an important role in FB reasoning, including the superior temporal sulcus, the temporoparietal junction and the medial prefrontal cortex [48, 49]. While Schneider, Slaughter [47] reported differences in brain activity between FB and TB conditions in the superior temporal sulcus, the rest of the mentalizing network was recruited equally during both conditions. This seems to indicate that both FB and TB conditions involve spontaneous belief processing.

However, our finding still raises the question as to why autistic individuals did not anticipate the protagonist's behaviour on the basis of reality or their own belief in the TB condition, as they did in the TB familiarization trials [34]. A comparison of these two types of TB trial reveals that the matched experimental trials are longer and additionally involve the protagonist turning away from the scene and, as such, experiencing a change of visual perspective; it is important to note that this change in perspective is belief-irrelevant (it does not result in a lack of knowledge about the location of the object). Previous studies have suggested that autistic individuals are competent in visual perspective taking level-1 (VPT-1, i.e. whether the protagonist has changed her perspective), but have difficulties in visual perspective taking level-2 [VPT-2, i.e. what she can see from her perspective; see review by 50]. It could be that our autistic participants ably process the head-turn cue and are therefore aware of the protagonist's perspective change (VPT-1), but struggle to appreciate the effect that the perspective change has on her knowledge of the object displacement thereafter (VPT-2) even though, in this instance, the perspective change has no effect on her knowledge. Accordingly, no prediction, or possibly two competing and opposing predictions, may have been generated about the protagonist's forthcoming action, which resulted in performance at chance level in our autistic adults. It seems therefore that it is at this early stage of mentalizing, as information from social cues is utilised to inform mental representations, that we find differences in autism.

Considering our additional FB condition (FBHD), neither the looking bias in either group nor any differences between groups were observed, consistent with findings from Wang and Leslie [33]. While these results might indicate that this condition failed to elicit mentalizing in the neurotypical adults, this explanation seems unlikely as the two FB scenarios differed only in the final location of the object. A more plausible explanation is that mentalizing test performance, as indexed by anticipatory eye gaze, is also subject to the availability of executive resources, especially inhibitory control [33, 51]. Both the TB bias hypothesis [33] and the similarity-contingency model [52] propose that individuals may default to utilizing their own mental states as a basis on which to mentalize about others. Taken together with the inhibition model of mentalizing proposed by Leslie and Polizzi [53], it seems likely that the inability to inhibit the specified TB in the FBHD may lead to greater uncertainty when predicting the protagonist's action [33].

Overall, we found that our multi-trial design was sensitive to detect group differences in mentalizing. We expected that increasing the number of trials would effectively decrease not only the dropout rate but also the error variance, addressing concerns from Dang, King [32] and Kulke, Wübker [29]. However, analysis of the timecourse of results indicated that the group difference only held across the eight trials in Block 1 but not the subsequent periods; the performance of the neurotypical group seemed to decrease over time, possibly due to fatigue or boredom (Frith, 2012). Accordingly, to maximise the sensitivity of the task, future research could remove the later blocks and the FBHD and TBST conditions, and instead increase the number of FBLD and TBLT trials in a single block.

In closing, we extended Southgate, Senju [19]'s paradigm to critically examine spontaneous mentalizing in autism through a multi-trial, multi-condition eye-tracking study with a more nuanced analysis of eye-movements over the timecourse of each trial. Replicating the findings of Senju, Southgate [21], we found that although many autistic individuals perform well in explicit mentalizing tasks, they do not engage in spontaneous mental state reasoning in implicit tasks, consistent with their everyday social difficulties. We have been able to rule out alternative theoretical explanations for this pattern of performance, leading to a better understanding of mentalizing in both neurotypical and autistic individuals. We have presented evidence that autistic adults are capable of processing information from social cues in the same way as neurotypical adults but that this information is not then used to update alternative mental representations. Future studies should directly test the point at which implicit mental state reasoning breaks down in autism.

Limitations

Although we have been able to address some important issues that until now have remained unanswered, an obvious limitation to this study was that our true-belief conditions may also trigger mentalizing. To create a mentalizing-free baseline condition for autistic individuals, matched as closely as possible to the FB condition, we suggest that future studies should replace the head-turn with another ‘filler’ action that would not trigger a change in visual perspective and therefore require mentalizing. Additionally, all participants were adults and had average-to-high IQs. Thus, our findings cannot be generalized to autistic adults with language delay and/or intellectual disability, or to autistic children. Still, this non-verbal paradigm holds promise as being adaptable to a much wider range of individuals than traditional mentalizing tests. Indeed, future studies should investigate whether spontaneous mentalizing varies between autistic individuals with different levels of general ability.

List of abbreviations

IQ: Intelligence quotient

ADOS-2: Autism Diagnostic Observation Schedule, Second Edition

TB: True-belief

FB: False-belief

TBST: True-belief short-turn

TBLT: True-belief long-turn

FBHD: False-belief high-demand

FBLD: False-belief low-demand

AOIs: Areas of interest

TFD: Total fixation duration

DLS: Differential looking score

WASI-II: Wechsler Abbreviated Scale of Intelligence, Second Edition

VPT-1: Visual perspective taking level-1

VPT-2: Visual perspective taking level-2

Declarations

Ethics approval and consent to participate

This study was approved by the UCL Research Ethics Committee, and written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Availability of data and materials

The dataset supporting the conclusions of this article is available in the Open Science Framework repository, https://osf.io/pts86/. Materials in the current study are available on request from the corresponding author.

Competing interests

The authors declare no potential con osf.io/pts86flicts of interest with respect to the research, authorship and publication of this article.

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Authors' contributions

The authors confirm contribution to the paper as follows: RW, SW and JL conceived and designed the study; JL filmed the stimuli; JL and ZA implemented the experiment; ZA collected the data, ZA, EA and IC conducted preliminary data analysis, RW performed the final data analysis, RW and SW interpreted the results and drafted the manuscript. All authors approved the final version of the manuscript.

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Tables

Table 1. *Descriptive statistics of participants' characteristics, Mean (Standard Deviation).*

	Autism (n = 17)	Neurotypical (n = 19)
Sex (M : F)	11 : 6	14 : 5
Age	36.71 (14.02)	31.79 (10.50)
Verbal IQ	121.35 (15.93)	120.05 (17.65)
Performance IQ	122.41 (21.30)	123.89 (19.68)
Full-scale IQ	123.53 (17.79)	124.05 (16.91)
ADOS [a]	8.44 (5.08)	

Note. [a] Autism Diagnostic Observation Schedule (data was unavailable for eight autistic participants).

Table 2. *Definition of each AOI.*

AOI_timeframe	Location	Event
Head_1	Protagonist's head area	The protagonist watches the puppet place the object in one of the boxes
Puppet_ 1	Puppet's moving area	
HeadTurn_2	Protagonist's head area	The protagonist turns away from the scene
Head_ 3	Protagonist's head area	The puppet displaces the object
Puppet_ 3	Puppet's moving area	
HeadTurn_4	Protagonist's head area	The protagonist turns back to the scene
Head_af	Protagonist's head area	From the onset of the alert signal to the end of the trial, total duration 4,800ms; for the long familiarization trials using opaque boxes, data were also encoded from the onset of the alert signal up until the protagonist reaches through the window, total duration 2,500ms
Belief-congruent	Window & box area consistent with protagonist's belief	
Belief-incongruent	Window & box area inconsistent with protagonist's belief	

Figures

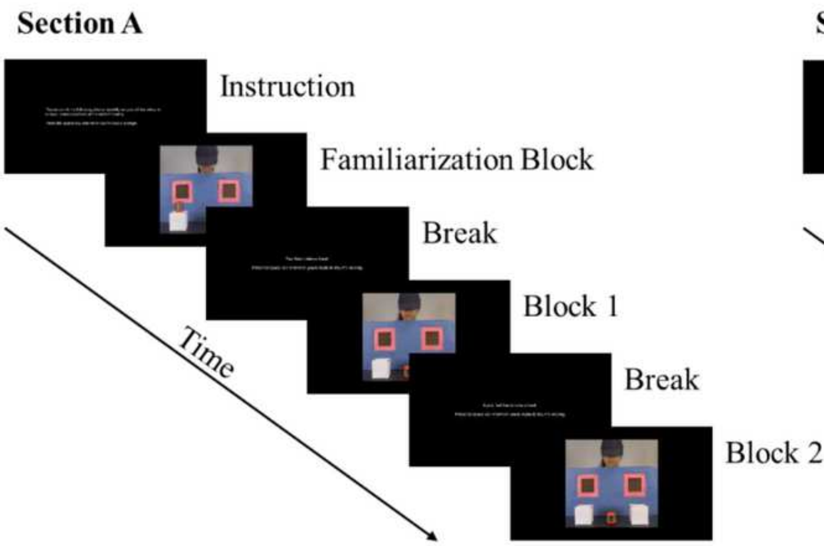

Figure 1

Implicit mentalizing task procedure.

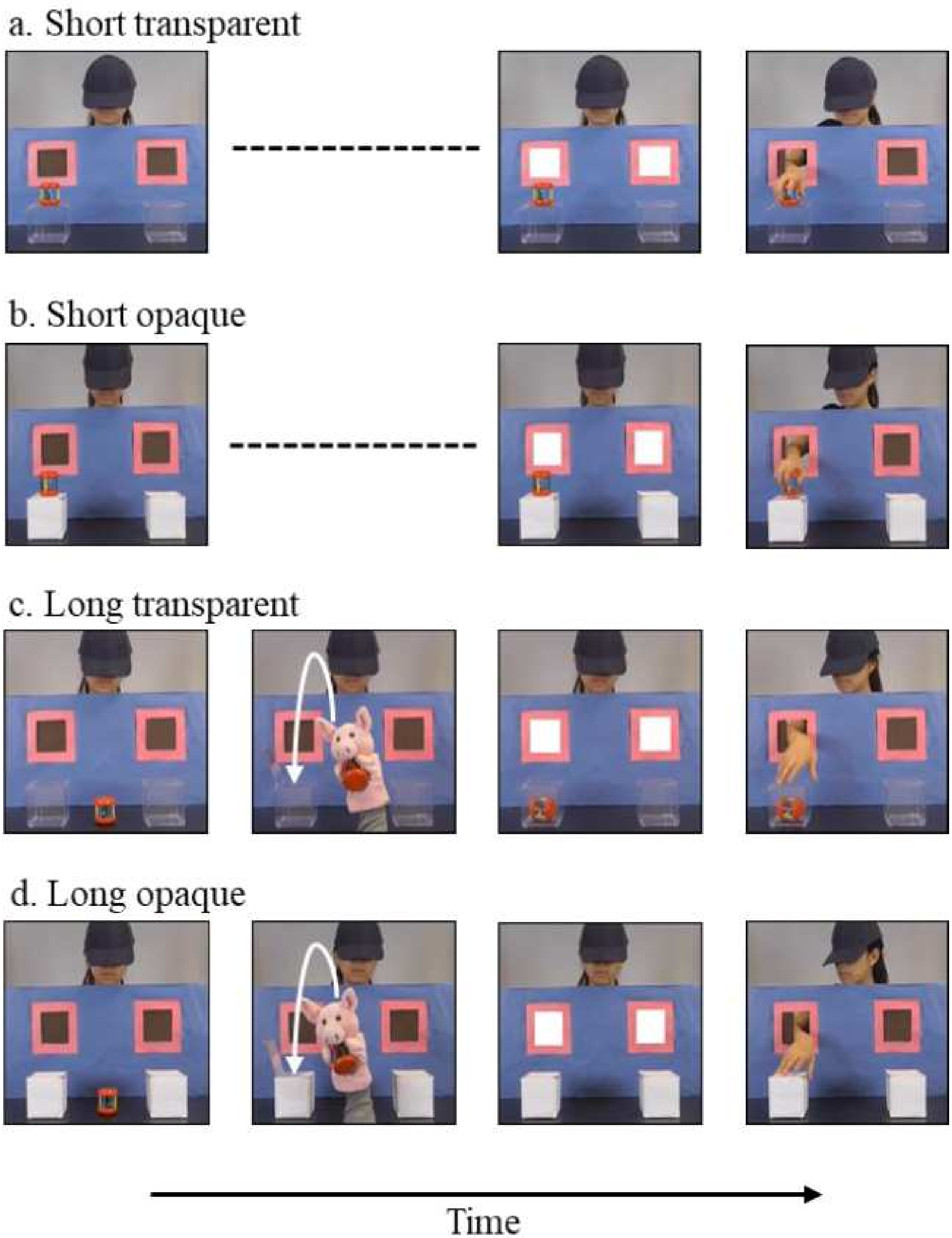

Figure 2

Short (5,000ms) and long (15,000ms), opaque and transparent familiarization trials. The scenarios of a and c were identical to b and d, respectively. Long familiarization scenarios include an additional object transfer event.

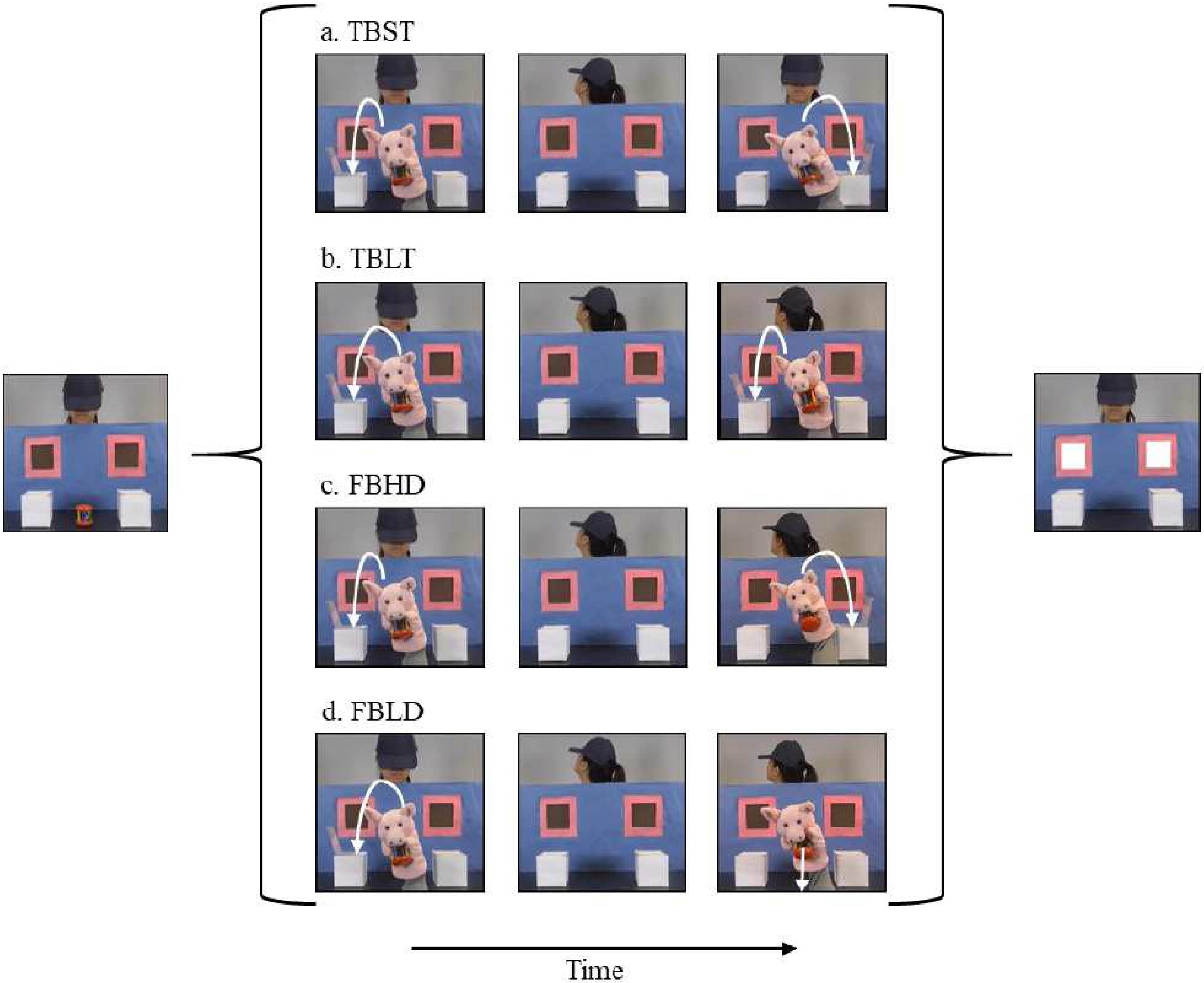

Figure 3

Sequence of events in the true-belief and false-belief condition videos (a) true-belief short-turn (TBST; 37,000ms), (b) true-belief long-turn (TBLT; 33,000ms), (c) false-belief high-demand (FBHD; 37,000ms), (d) false-belief low-demand (FBLD; 33,000ms).

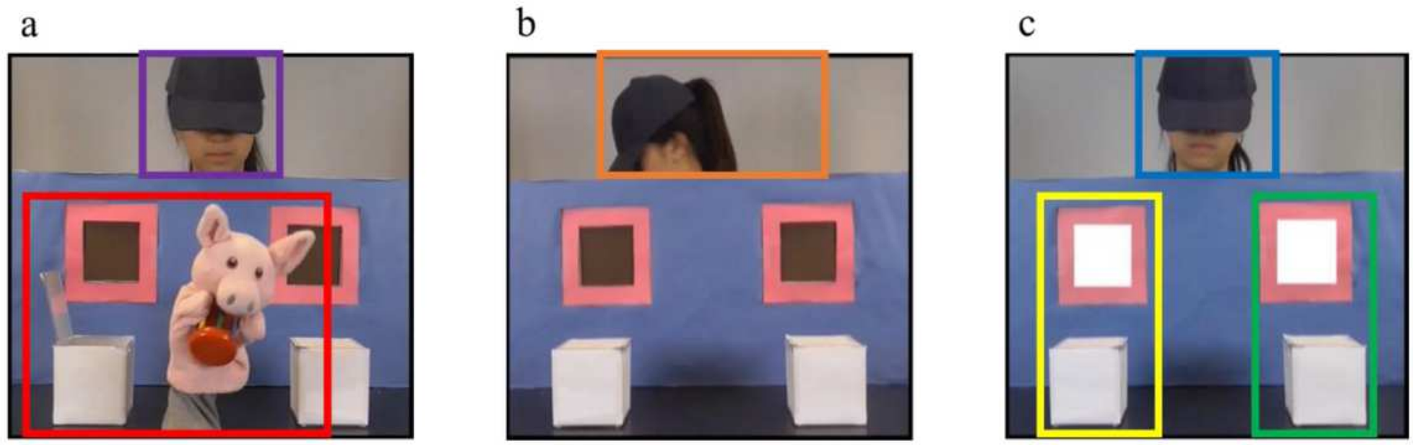

Figure 4

Location of the AOIs. a. Head_ 1 and Head_ 3 (purple), Puppet_ 1 and Puppet_ 3 (red); b. HeadTurn_2 and HeadTurn_4 (orange); c. Head_af (blue), Belief-congruent (yellow) and Belief-incongruent (green).

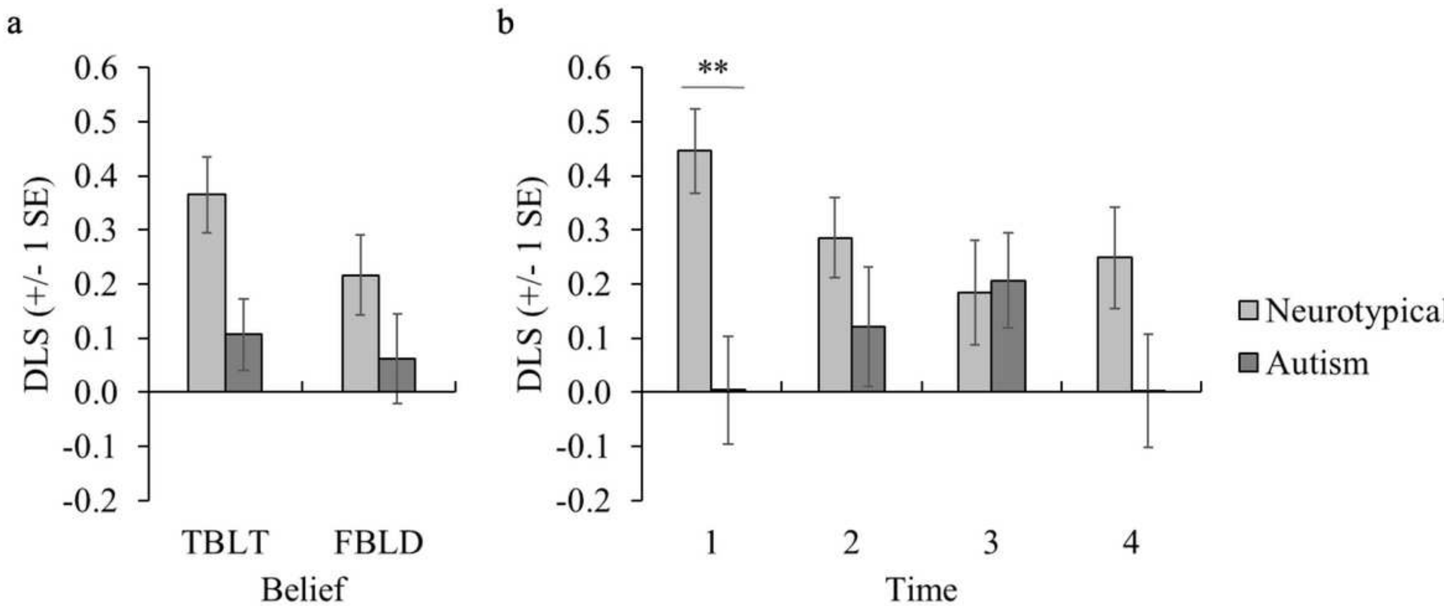

Figure 5

Mean DLS indicated (a) a main effect of Group (b) a Group*Time interaction. Post-hoc analysis revealed that a group difference was only present at Block 1. ** p ≤ .001.

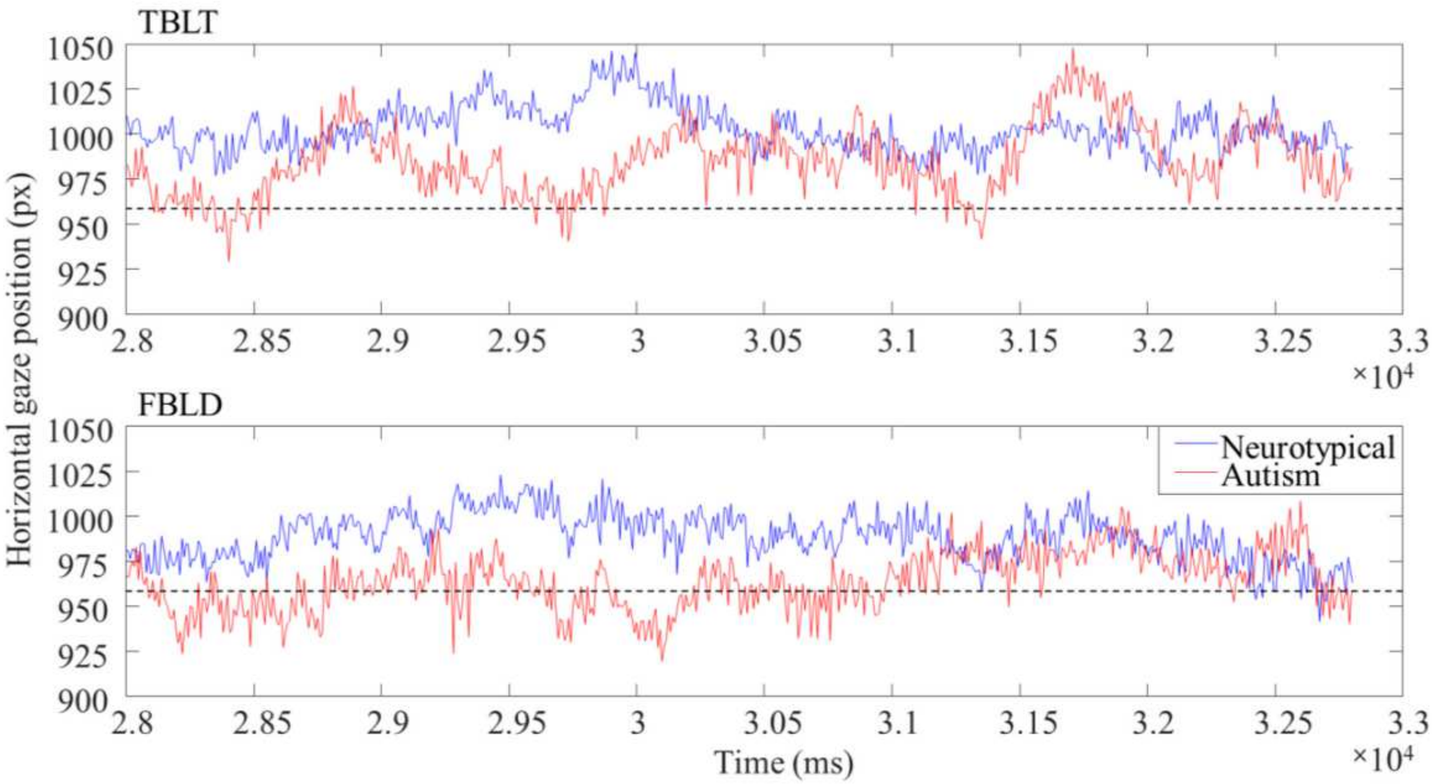

Figure 6

Grand averaged horizontal gaze position in response to stimulus presentations across conditions TBLT and FBLD. This timeframe begins at the onset of the alert signal until the end of the video, from 2.8 to 3.28x104ms. The origin (0 px) of the frame is defined as the edge of the screen on the belief incongruent side. The dashed line indicates the midline of the screen. Values above the dashed line are therefore biased towards the Belief-congruent side of the screen.

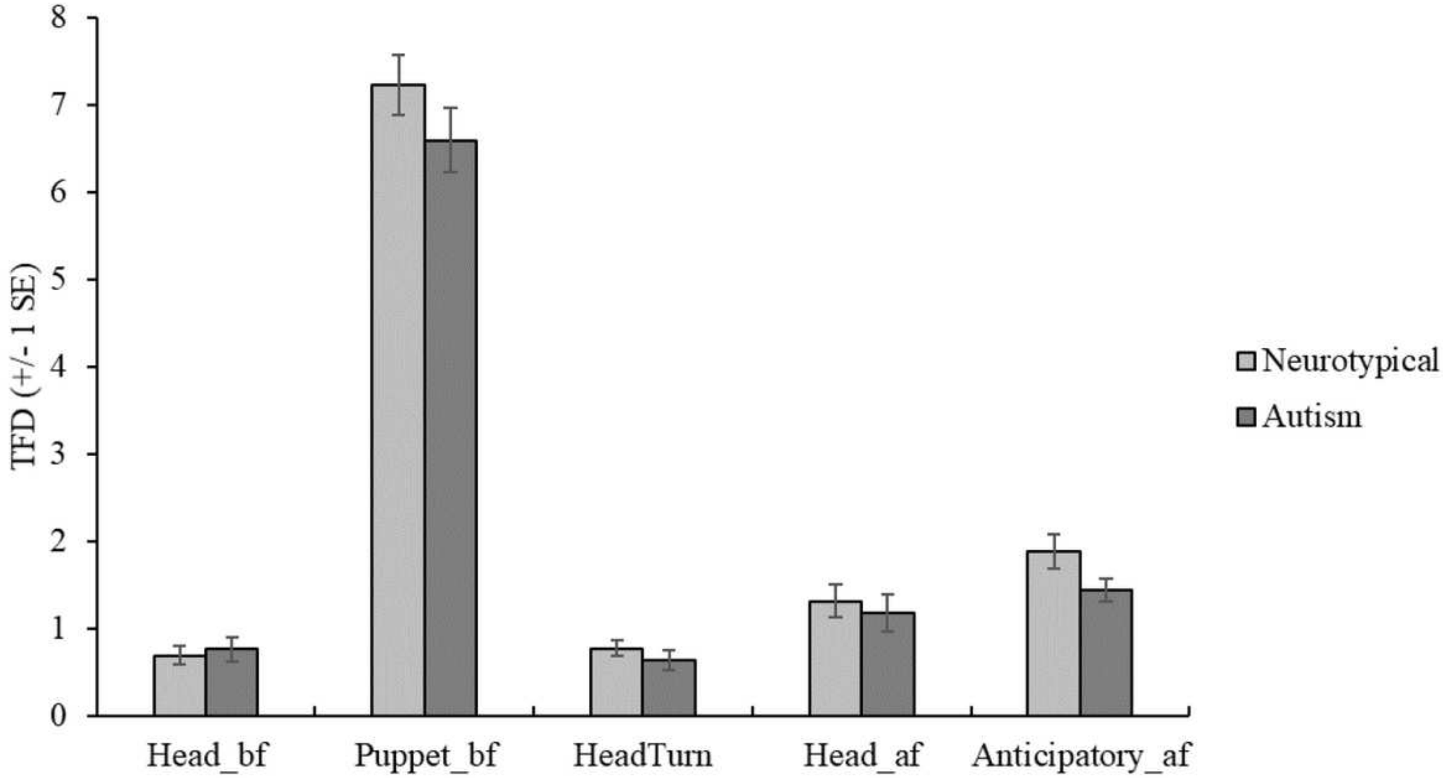

Figure 7

Mean TFD indicated no group difference in all AOIs.

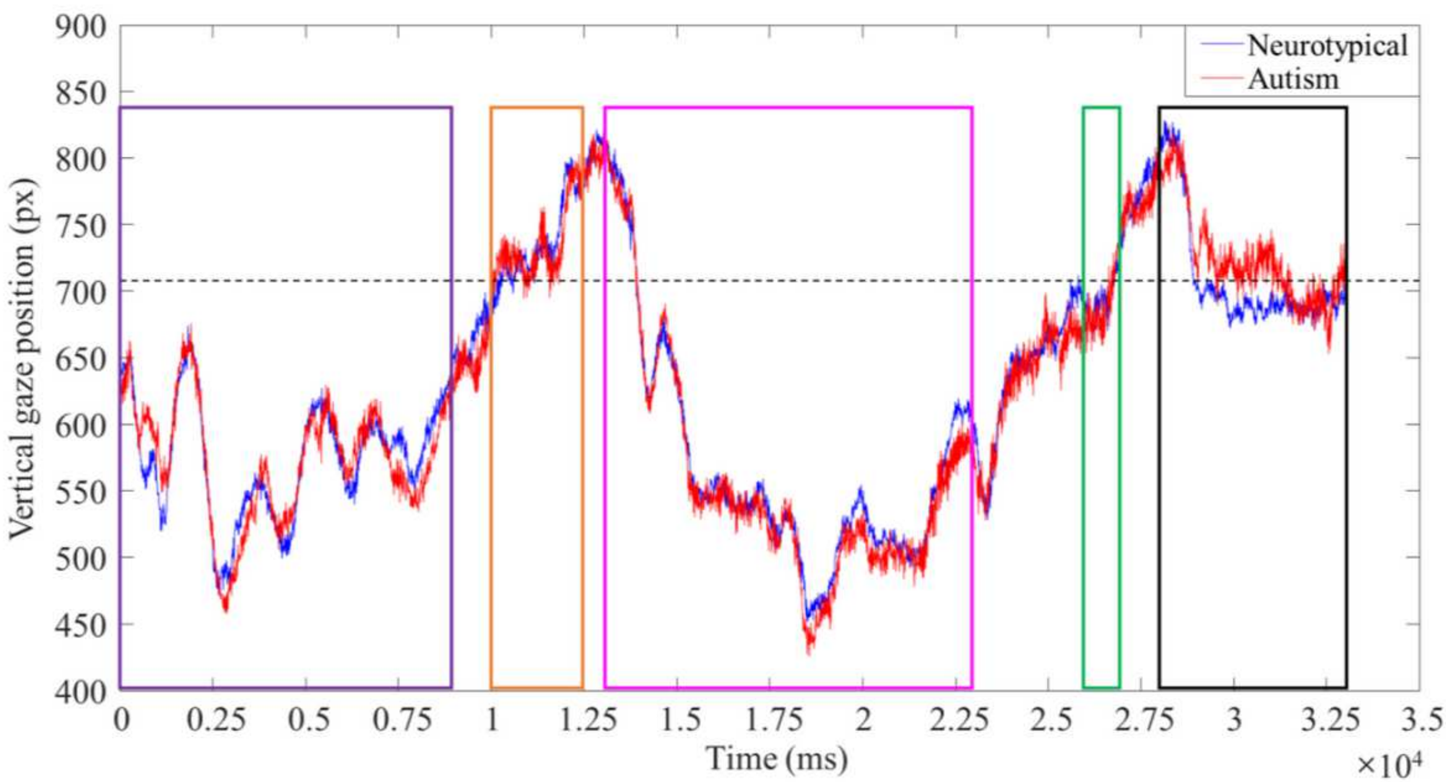

Figure 8

Grand averaged vertical gaze position in response to stimulus presentations across condition TBLT and FBLD. Timeframe 1: Head_ 1 and Puppet_ 1 (purple), Timeframe 2: HeadTurn_2 (orange), Timeframe 3: Head_ 3 and Puppet_ 3 (pink), Timeframe 4: HeadTurn_4 (green), Timeframe 5: Head_af and Anticipation_af (black). Video onset occurred at 0ms. The origin (0,0) of the frame is in the bottom left corner of the screen. The dashed line indicates the edge of the purple board in the scene.