Atypical Processing Pattern of Gaze Cues in Dynamic Situations in Autism Spectrum Disorders

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Abstract

Psychological studies have generally shown that individuals with Autism Spectrum Disorder (ASD) have specificity in the processing of social information by using static or abstract images. Yet, a recent study showed that there was no differ in their use of the added social or non-social cues in dynamic interactive situations. To establish the cause of the inconsistent results, we explored the processing pattern of gaze cues in individuals with ASD by using chase detection paradigm and eye-tracking methodologies. In this study, unlike typical controls, participants with ASD showed no detection advantage under the oriented condition. The results suggested that individuals with ASD may utilize an atypical processing pattern in dynamic interactive situations.

Background

Autism Spectrum Disorder (ASD) is a group of neural developmental disorders with repetitive behaviors and restricted interests as the core features of social interaction and communication disorders (American Psychiatric Association, 2013). These symptoms manifest in many areas of people's development, such as verbal communication, behavioral responses, and establishment of social relationships. Recent studies have shown that individuals with ASD have specificity in the processing of information containing social meaning, and their cognitive competences are different from others (Weisberg et al., 2014). For many typically developing (TD) individuals, detection of other people's gaze direction, head orientation and other information in social interactions occurs spontaneously (Hamilton, 2016; Kaisler, & Leder, 2017; Otsuka, Mareschal, Calder, & Clifford, 2014; Slessor et al., 2016). These behavior patterns can help people infer the attentional focus, mental state and behavioral intention of others. However, it is hard for ASD to process social information in this way. It has been proposed that the developing mind has an "intentionality detection" mechanism, which is an early precursor to other social cognitive developments (Baron-Cohen, 1991; Baron-Cohen, 1995; Phillips, Baron-Cohen, & Rutter, 1998). Disruption in the development of this mechanism may explain why it is difficult for individuals of ASD to perceive the intentionality and interactions between objects using visual information (McAleer, Kay, Pollick, & Rutherford, 2011). Children with ASD tend to avoid another person's gaze and have difficulties in processing social cues (Langton et al., 2000). Researchers have used social (eye, face orientation) and non-social orientation cues (chair orientation) to explore the orientation adaptation of ASD, and found that they have poorer ability to adapt to orientation cues in social situations (Lawson, Aylward, Roiser, & Rees, 2018). This may lead to atypical development of their social cognition, such as the difficulty in comprehending and explaining another's behavior, as well as guidance of their own behavior based on such information. Therefore, exploring the mechanism of their social information processing will help to better understand how individuals with ASD process external information and ultimately to improve intervention and treatment.

Gaze cues are commonly used in research on social information processing (Frischen, Bayliss, & Tipper, 2007; Hamilton, 2016; Jording, Engemann, Eckert, Bente, & Vogeley, 2019). The evidence from eye movement research suggested that individuals with ASD are responsive to gaze as a perceptual cue but ignore its representational meaning. Congiu et al. (2016) used eye-tracking methodology to compare spontaneous gaze following in young children with ASD to that of children. The results showed that the processing of gaze cues in children with ASD was mainly driven by perceptual features, such as the position of the irides in the sclera, rather than information about social significance provided by gaze cues. Klin et al. (2002a) analyzed the visual scanning paths of the adult viewers with autism to verbal and non-verbal cues in a social scene from a film. The results suggested that the viewer with ASD responded primarily to the verbal cue and neglected the non-verbal gesture. But when the participant was later questioned, in an explicit fashion, about whether he knew what the pointing gesture meant, he had no difficulty defining the meaning of the gesture. And yet, he failed to apply this knowledge spontaneously when viewing the scene from the film. These studies suggested that individuals with ASD have an atypical processing pattern for gaze cues.

In real life, gaze cues are often associated with other social movements such as approach and escape, but previous studies have rarely put these cues into some type of dynamic situation. Instead, gaze cues are presented as static or abstract images as well as simple displays of head spinning (Grynszpan et al., 2019; Zhao, Uono, Yoshimura, Kubota, & Toichi, 2017). Therefor, we used a special experimental paradigm called chase detection, in which gaze cues are added to moving subjects. In this paradigm, originally designed by Gao, Newman and School (2009), a ball (referred to as ‘wolf’) is chasing another (referred to as ‘sheep’) and this chasing behavior was defined by the degree to which the wolf reliably moved in the direction of the sheep. Accuracy for identifying chasing behavior can be evaluated under different levels of difficulty by manipulating chasing subtlety (set by adjusting the angular deviation of the heading of the wolf relative to the sheep) and three different orientation gaze cues to explore their influence on chase detection by TD individuals. The results showed that the accuracy was significantly higher under oriented gaze cue conditions than under perpendicular and reverse cue conditions. The phenomenon that the alignment of gaze direction and movement direction can significantly improve the chase detection efficiency of individuals is called oriented advantage, and it is considered one of the typically processing patterns of gaze cues in dynamic situations.

By adding gaze cues to the paradigm, Vanmarcke and his colleagues recently tested the role of social interpretations of adolescents with and without ASD (Vanmarcke, Van de Cruys, Moors, & Wagemans, 2017). Their results showed that the ASD group was less accurate than the control group and the accuracy of both groups was better in the social condition than in the non-social condition. But there was no interaction between group and condition. This may indicated that adolescents with and without ASD did not differ in their use of the added social or non-social cues. The intact performance of adolescents with ASD in this study seems inconsistent with the view of deficit social cognition.

The theory of enactive mind (EM) offers an approach to social cognitive development intended to explain how individuals with ASD search for meaning when presented with naturalistic social scenes (Klin, Jones, Schultz, & Volkmar, 2003). It proposes a developmental hypothesis of autism in which the process of acquisition of embodied social cognition is derailed early on, as a result of reduced salience of social stimuli and concomitant enactment of socially irrelevant aspects of the environment. Further, individuals with ASD seem to be fully capable of collecting social information, but cannot learn the social meaning represented by the information nor how to translate it into socially adaptive behaviors (Klin, Jones, Schultz, Volkmar, & Cohen, 2002a, b). Therefore, we speculate that the reason why social cues had a positive effect on the performance of the participants with ASD in the Vanmarcke et al. study may be due to their distinctive processing mode of social cues. In other words, these cues may have physical, but not social, implications for individuals with ASD. In addition, the design of Vanmarcke et al. experiment was unable to explore the processing patterns of individuals by comparing their performance to gaze cues in different directions. It's a computer-based behavioral experiment, unable to further explore other indices related to potential processing mechanisms.

Therefore, we wanted to explore the processing pattern of gaze cues in individuals with ASD by using chase detection paradigm and eye-tracking methodologies. We mainly focused on two questions in our experiment. The first was whether there is a difference between the processing mode of gaze cues in individuals with or without ASD in a dynamic chasing context. The second question examined the influence of a variety of gaze cues on the visual processing and cognitive processing in the chase detection process. We set three kinds of gaze cues: oriented, reverse, and perpendicular.

This not only ensured that the physical characteristics are highly similar, but also enabled to know the differences in the processing patterns of the participants through the comparison of the cues. If the participants had a typically processing mode, we predicted that participants: 1) could understand the social information contained in gaze cues, 2) would pay more attention to where the gaze cues are pointing, and 3) oriented gaze cues would be effective cues for participants to detect the chase, while reverse and perpendicular gaze cues would hinder detection. However, if participants had an atypical processing mode, they would not have the oriented advantage. In addition, to further explore the participants' visual and cognitive processing, eye movement tracking methodology was combined with the behavioral assay. This study assumed that participants with ASD use an atypical processing pattern in the chase detection task, consistent with the viewpoint of EM.

Methods

Participants.

Twenty adults with ASD were recruited for this study (4 females and 16 males). We excluded two males with ASD because they failed to pass the calibration procedure. Thus, the final sample consisted of eighteen adults with ASD. They were recruited from the Aina autism service center in Dalian, and had been diagnosed based on Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V) (American Psychiatric Association, 2013). All diagnoses were completed at the qualified hospitals (e.g., Peking University Sixth Hospital). The control group consisted of eighteen individuals recruited through bill-posting (4 females and 14 males, mean age=19.51, *SD* = 0.98). IQ was measured using the Chinese version of Wechsler Adult Intelligence Scale - Third Edition (WAIS-III; Wechsler, 1997). Detailed descriptions of participant characteristics can be found in Table 1. There were no significantly differences between the ASD and control groups in chronological age, verbal IQ, performance IQ, and full-scale IQ. All participants had normal or corrected-to-normal vision.

The research was conducted according to the principles of the Declaration of Helsinki and was approved by the Ethical Committee of School of Psychology at Liaoning Normal University. We checked whether the participants with ASD were capable of understanding the task requirement through interviews. We obtained written informed consent from all participants and their parent and/or legal guardian. They were debriefed and thanked following their participation.

Table 1

Participant characteristics for ASD and TD groups.

		ASD group	TD group	*Statistic*	*p*
N		18	18		
Age	Mean	20.84	19.51	$t\,(34) = 1.623$	0.114
	SD	3.36	0.98		
Gender ratio	Females	4	4	$c^{2}(1) = 0.000$	1.000
	Males	14	14		
WAIS IV Verbal IQ	Mean	96.01	102.22	$t\,(34) = 1.864$	0.071
	SD	11.25	8.61		
WAIS IV Performance IQ	Mean	106.78	109.28	$t\,(34) = 0.985$	0.332
	SD	8.43	6.70		
WAIS IV Full Scale IQ	Mean	105.01	108.22	$t\,(34) = 1.122$	0.270
	SD	9.33	7.83		

Material.

The displays were made by Matlab2014a and presented on a PC computer. Each of them contained four green balls (apparent size: 1° of visual angle) with two red eyes shown for 10000 ms. We made references to the experimental material design of Gao et al.(2009) and Vanmarcke et al.(2017). At the start of each trial, three of the balls started moving at a constant speed of 14.5°/s and moved haphazardly by randomly changing direction within a 120° window (approximately every 170 ms). The fourth ball was termed the 'wolf ' and moved differently. The heading of the wolf towards the sheep (the ball being chased), was manipulated by altering its maximal angular deviation (chasing subtlety). We set three different chasing subtleties: 15°, 45°, and 75°. For example, when the chasing subtlety was 15°, the wolf could move in any direction within a 30° window which always centered on the sheep (Fig. 1). To maintain a similar movement pattern, the wolf chased an invisible ball in chase-absent trials, whereas it chased one of the three visible balls in chase-present trials. Furthermore, the chasing behavior of the wolf was delayed for 170 ms at the start of each trial in order to make the chasing appear smoother.

We also set three conditions. In oriented conditions, the direction of red eyes always matched the directions in which they are moving. In reverse conditions, the balls moved in opposite direction to the direction of red eyes. In perpendicular conditions, the orientation of the eyes was always perpendicular to the direction of the balls' motion (Fig. 1).

Procedure.

The displays were presented on a 21inch DELL computer with a 60 Hz refresh rate and 1024×768 pixel resolution, and were viewed from 60 cm in a dimly lit room. Eye movements were recorded monocularly by Eyelink 1000 with a sampling rate of 1000 Hz and a spatial resolution of 1°. Each participant was instructed to position their chin in a chin rest to hold their head stationary and to avoid blinking as much as possible during each trial.

Before each block, participants completed a five-point calibration phase. After successful completion of the calibration phase, they were told to observe the stimuli displayed on the screen. An experimenter operated the eye tracker from a laptop computer not visible to the participants.

The test phase included 3 blocks (conditions) and took about 30-40 minutes. All participants completed 39 trials per condition (13 per chasing subtlety, of which 10 were chase-present and 3 were chase-absent trials). Then participants completed a training phase to make sure they comprehended the instructions. After each trial, they were given visual feedback. Training ended when the participant responded correctly in 6 consecutive trials. These trials were not included in the formal analysis.

All instructions were provided on the computer screen, and every trial started with a 1-second fixation before the chasing display was presented (Fig. 2). The eye tracker recorded the participant's eye movement during the 10-second animation. At the end of each trial, the participants were required, without time constraints or feedback, to indicate whether or not the trial contained a chase. All participants had to complete all three blocks presented in a counterbalanced order.

Data analysis.

Some researchers suggested that two visual exploration strategies which are used by participants to detect a chase: either following 1 agent for a certain amount of time (and jumping to another agent until a chase is detected), or looking roughly at the barycenter of all four agents, thus obtaining an optimal view of the movements of all agents simultaneously (Fehd & Seiffert, 2008; Lukavský, 2013). In order to determine the strategies of participants through eye movement data, we set two dynamic areas of interest (AOIs) on each display for analysis. Based on these AOIs, we calculated five indicators: agent-looking rate, barycenter-looking rate, stray-looking rate, ocular sensitivity and cognitive sensitivity.

Agent-looking rate was defined as the ratio of fixation count of AOI1 (FC1) to the sum of FC1 and FC2. Barycenter-looking rate was defined as the ratio of fixation count of AOI2 (FC2) to the sum of FC1 and FC2. Stray-looking rate was defined as the proportion of gaze falling anywhere else (excluding AOI1 and AOI2). Because agent- and barycenter-looking rate are complementary, we analyzed all indicators except barycenter-looking rates.

We also used a previously described measure related to the distribution of gaze across the 4 agents: the agent preference index (API), defined as the standard deviation (SD) of looking rates on each of the 4 agents (Ramus, Passerieux, & Roux, 2015). The idea is that if participants detect the chase, they will tend to track the sheep and the wolf and, hence, will show unevenly distributed looking rates across agents and a high SD. In contrast, if they detect no chase, all agents should have an equal probability of being tracked, and the SD should be lower. Thus, API provided a measure of participants' implicit detection of chasing, independent from the explicit response. Two additional sensitivities were derived from the API using the same signal detection approach as for the chasing detection sensitivity. Ocular sensitivity measures the extent to which the API reveals the implicit detection of chasing. Cognitive sensitivity measures the extent to which explicit chase responses reflect the implicit detection of chasing. Cognitive sensitivity is thus more related to highlevel decisional processes about intentional information. This was calculated as:

Sensitivity: d'= z(H) - z(F)

H is the hit (correctly detecting a chase) rate, F is the false-alarm (saying a chase exists when one did not) rate and z is the inverse function of the normal distribution. Null values of H and F were replaced by 1/2N, with N being the number of trials per participant (39). When H and F were equal to 1, they were replaced by 1-1/2N.

Results

Behavioral data.

Total fixation duration of AOI1 and AOI2(s) that were less than 3 SD above their group's mean were excluded from the analysis (2% of trials). The behavioral data were analyzed with a 2 (group: ASD, TD)×3 (chasing subtlety: 15°, 45°, 75°)×3 (type of gaze-cues: oriented cues, reverse cues, perpendicular cues) repeated measures analysis of variance (ANOVA), which revealed significant main effects of group, $F(1, 34) = 12.20$ $p = 0.001$ $\eta_p^2 = 0.26$, a main effect of chasing subtlety, $F(2, 68) = 72.17$ $p < 0.001$ $\eta_p^2 = 0.68$, a main effect of the type of gaze-cues, $F(2, 68) = 6.07$ $p = 0.004$ $\eta_p^2 = 0.15$, and a reliable interaction between chasing subtlety and the group, $F(2, 68) = 14.20$ $p < 0.001$ $\eta_p^2 = 0.30$. Therefore, we performed

Bonferroni post hoc test to further analyzed the interaction. TD group's accuracy with 15° of chasing subtlety [mean = 0.98 *SD* = 0.04] was higher than ASD group [mean = 0.77 *SD* = 0.23] ($p < 0.001$). Their accuracy in the 45° condition [mean = 0.92 *SD* = 0.07] was also higher than the ASD group [mean = 0.76 *SD* = 0.16] ($p < 0.001$). But in the 75° condition, TD group's accuracy [mean = 0.66 *SD* = 0.14] ($p < 0.001$) was similar to ASD group [mean = 0.65 *SD* = 0.19] ($p = 0.78$).

We also found a significant interaction of all three factors, $F(4, 136) = 3.01$ $p = 0.013$ $\eta_p^2 = 0.09$. Post hoc analyses showed that in the 15° and 45° chase subtlety conditions, the accuracy of the TD group was higher with all types of gaze-cues than the ASD group. However, the accuracy of the two groups was similar in the 75° condition. Moreover, in the 75° chase subtlety condition, the TD group's accuracy with oriented cues [mean = 0.77 *SD* = 0.12] was higher than with reversed [mean = 0.59 *SD* = 0.15] ($p < 0.001$) or perpendicular cues [mean = 0.63 *SD* = 0.14] ($p = 0.007$), the ASD group's accuracy showed no significant difference between three types of gaze cues (Fig. 4).

Eye-tracking data.

The data of agent-looking rate were subjected to a 3-factor repeated measures ANOVA, which revealed significant main effects for group, $F(1, 34) = 55.01$ $p < 0.001$ $\eta_p^2 = 0.62$, chasing subtlety, $F(2, 68) = 22.67$ $p < 0.001$ $\eta_p^2 = 0.40$, and type of gaze-cues factors, $F(2, 68) = 8.47$ $p = 0.001$ $\eta_p^2 = 0.20$. It also yielded a significant interaction between gaze-cues and group factors, $F(2, 68) = 8.61$ $p < 0.001$ $\eta_p^2 = 0.20$. Post hoc analyses showed that ASD group's agent-looking rate of the three kinds of gaze-cues were all higher than the TD group. In the TD group, agent-looking rates with oriented cues [mean = 0.56 *SD* = 0.07] were higher than their rates with reversed cues [mean = 0.50 *SD* = 0.08] ($p < 0.001$) or perpendicular cues [mean = 0.51 *SD* = 0.07] ($p < 0.001$). However, there was no significant effect of gaze-cue on the ASD group (Fig. 5).

The data of stray-looking rate were submitted to a 3-factor repeated measures ANOVA. This analysis identified significant main effects of group, $F(1, 34) = 12.37$ $p = 0.001$ $\eta_p^2 = 0.27$, chasing subtlety, $F(2, 68) = 6.23$ $p = 0.003$ $\eta_p^2 = 0.16$, as well as a significant interaction between gaze-cues and group factors, $F(2, 68) = 4.09$ $p = 0.021$ $\eta_p^2 = 0.11$. Post hoc analyses showed that the ASD group's stray-looking rates for the three kinds of gaze cues were significantly higher than the TD group. For the TD group, stray-looking rates with oriented cues [mean = 0.37 *SD* = 0.04] were lower than their rates with reversed cues [mean = 0.41 *SD* = 0.04] ($p = 0.006$) or perpendicular cues [mean = 0.40 *SD* = 0.05] ($p = 0.004$). However, there were no significant cue-related effects on the stray-looking rates of the ASD group (Fig. 6).

The data for ocular sensitivity were subjected to a 3-factor repeated measures ANOVA. This analysis identified significant main effects for the group, $F(1, 34) = 23.43$ $p < 0.001$ $\eta_p^2 = 0.41$, and chasing subtlety factors, $F(2, 68) = 10.45$ $p < 0.001$ $\eta_p^2 = 0.24$. It also yielded a significant interaction between type of gaze-cues and group factors, $F(2, 68) = 3.17$ $p = 0.048$ $\eta_p^2 = 0.09$. The ASD group's ocular sensitivity to oriented cues [mean = 1.31 *SD* = 0.39] were significantly higher than those of the TD group [mean = 1.09 *SD* = 0.28] (p = 0.004), and their ocular sensitivity to perpendicular cues [mean = 1.32 *SD* = 0.38] were significantly higher than those of the TD group [mean = 1.00 *SD* = 0.29] (p < 0.001). But there were no group differences for the reversed cues (Figure. 7).

The data for cognitive sensitivity were analyzed with a 3-factor repeated measures ANOVA. This analysis found significant main effects of group, $F(1, 34) = 15.93$ $p < 0.001$ $\eta_p^2 = 0.32$, and chasing subtlety factors, $F(2, 68) = 25.95$ $p < 0.001$ $\eta_p^2 = 0.43$. It also found a significant interaction between chasing subtlety and group factors, $F(2, 68) = 6.36$ $p = 0.003$ $\eta_p^2 = 0.16$. Like the result of behaviour data analyses, in the 15° condition, the ASD group's cognitive sensitivity [mean = 0.72 *SD* = 0.32] were lower than TD group [mean = 1.02 *SD* = 0.28] (p < 0.001). In the 45° condition, the ASD group's cognitive sensitivity [mean = 0.69 *SD* = 0.30] were lower than TD group [mean = 0.95 *SD* = 0.28] (p < 0.001), but not in the 75° condition (Figure. 8).

Discussion

In this study, the chase detection paradigm was used to compare the way that individuals with and without ASD processed gaze cues in dynamic interactive situations, and the eye-tracking method was used to explore the impact of gaze cues on their visual and cognitive processing during detection.

Our behavioral data show that in the low (15°) and moderate (45°) chasing subtleties, the influence of directional gaze cues did not appear to have obvious effects on accuracy of detection of either group. Under the high (75°) chasing subtleties, on the other hand, participants were influenced more by gaze cues. This suggests that when the task is of moderate difficulty, individuals will rely more on agents themselves to detect the chase, such as the way they move and how far away they are. When the chase subtlety cues provide less helpful information to accurately detect a chase, the role of gaze cues will be revealed (that is also the meaning of setting the chasing subtleties). Further analysis shows that when the chasing subtlety is high, the accuracy of the TD group under the oriented condition is significantly higher than that under the reverse or perpendicular cue conditions. These participants showed a detection advantage under oriented conditions, which was similar to previous studies (Gao, McCarthy, & Scholl, 2010; Scholl & Gao, 2013). In contrast, ASD group showed no detection advantage under the oriented condition. When the chasing subtlety was high, there was no significant difference in their accuracy between the oriented condition and the other two gaze cue conditions, results consistent with our hypothesis.

Defects of executive functions, such as response inhibition and poor cognitive flexibility, will affect keyboard responses of ASD group, thereby preventing behavioral data from revealing their processing pattern. To overcome this bias, we collected eye movement data during chase detection trials. These data were incorporated into the working model of chase detection described by Roux and his colleagues (2015) to further comprehend detection processing of ASD participants.

According to this model, the process of chase detection includes two aspects. The first is attention to the stimulus, which is mainly represented by the stray-looking rate describing the effects of low-level eye movement factors. The second is exploration, which includes the visual response stage and the behavioral response stage. Visual responding is measured by ocular sensitivity which represents the extent to which the API reveals the implicit detection of chasing. The behavioral response stage is measured by cognitive sensitivity which shows the extent to which explicit chase responses reflect the implicit detection of chasing. In addition, an individual's exploration strategies are mainly determined by their agent-looking rates. Accordingly, we will discuss the influence of gaze cues on the two stages of chase detection processing.

Previous studies have provided evidence of how eye movement patterns reflect global processing strategies (Bombari, Mast, & Lobmaier, 2009; Kucharský et al., 2020; Lemieux, Collin, & Nelson, 2015). In our eye-tracking data analysis, the proportions of each participant's eye gaze located within different areas of interest were calculated (agent-looking rate and stray-looking rates). We noticed that when TD participants detected the chase among four moving balls, they focused more on the central area of the balls rather than on individual balls. This suggested a processing strategy whereby TD participants tended to integrate multiple stimuli by paying close attention to their displacement relationships with each other. Under the oriented condition, the agent-looking rates of the TD group were significantly higher than these rates in other conditions. This suggested that the oriented gaze cues helped the TD group detect chasing by enabling the participants to direct their eye gazes more to each agent than on the center of the agents.

For the ASD group, the agent-looking rate was approximately 0.63, significantly higher than that of the TD group, whether under the oriented, perpendicular or reverse cue conditions. This suggests that young adults with ASD are less likely to adopt the integral detecting strategy and more inclined to locate and process agents separately, regardless of the nature of the cue. These participants were insensitive to the gaze cues and were not good at adjusting detection strategies according to the different directions of the gaze cues. Our finding is consistent with a weak central cognitive processing style of ASD (Happé & Frith, 2006; Skorich et al., 2016).

This viewpoint was also supported by the behavioral results showing that the chase detection accuracy of the two groups decreased as the difficulty of the chase subtlety increased, and the TD group had a greater reduction than the ASD group. This difference indicates that the chase detection performance of ASD group was less dependent on chasing subtlety than that of TD. These results were similar to those of Vanmarcke et al. (2017). They suggested that the processing of the motion relationship between agents has lost its saliency with higher chasing subtlety and a more attention-focused processing of each of the moving balls gradually became a better search strategy.

Previous studies in the field of social attention have shown that individuals with ASD process social information differently from TD individuals. Vlamings et al. (2005) examined reflexive visual orienting following eye direction or symbolic (arrow) cues, either congruent or incongruent with target presentation, in persons with and without ASD. These investigators found that both the incongruent eye direction cues and the arrow cues enabled individuals with ASD to detect the direction of a target more quickly. This indicates that instead of a specific 'eye direction detector', persons with ASD might have a general 'symbol direction detector'. Other researchers found that eye gaze cues attracted attention more effectively than the arrow in TD children, while children with ASD shifted their attention equally in response to eye gaze and arrow direction, suggesting they failed to show preferential sensitivity to the social cue (Senju, Tojo, Dairoku, & Hasegawa, 2004). Combining behavioral and eye movement data, we guessed that the TD group socialized the gaze cues by focusing more on where the gaze is pointing. In the oriented condition, there was the ball being chased in the range indicated by the line of sight, which helped TD participants detect a chase. However, under the reverse and perpendicular conditions, the range of the line of sight was not followed by the chased ball, and the inconsistency between the line of sight and the direction of motion violated their social perception (Lawson, Aylward, Roiser, & Rees, 2018; Schultz & Bülthoff, 2013; Tremoulet & Feldman, 2000). Therefore, their detection accuracy was lower under these two conditions. But individuals with ASD are different from them, and there may be no difference in processing pattern between social cues and non-social cues.

Moreover, Šimkovic and Trauble (2015) explored the role of eye movements in the detection of chasing. They argued that subjects do not compare the movement of the pursued pair to a singular template that describes a chasing motion. Rather, subjects bring certain hypotheses about what features of motion may qualify as chase and then, through feedback, they learn to look for a motion pattern that maximizes their performance. However, we did not observe this gradually optimized processing strategy in the eye movement data of the ASD group whose agent-looking rates were comparable in all gaze cue conditions. This indicated that their visual detection strategy was relatively stable not affected by gaze cues. This result also confirmed the EM hypothesis that individuals with ASD have difficulty changing their strategies to adapt to a change in the environment (Colombetti, 2012; Klin, Jones, Schultz, & Volkmar, 2003).

The results of sensitivity analysis showed that the ocular sensitivity of participants with ASD was generally higher than that of the TD group, while the cognitive sensitivity was generally lower. It revealed that the implicit, early and online detection of chasing was intact in participants with ASD. Their eye movements were more related to the presence of a chase, suggesting that they may have more often produced ocular detection of chasing and the chasing information had been correctly processed at the visual level. Furthermore, their preferred local looking strategy partly explained the increased ocular sensitivity. The decreased cognitive sensitivity revealed diffculties deciding whether a chase was present or not and/or producing the appropriate response, even when their eye movement (Ramus, Passerieux, & Roux, 2015). This result may have some implications for the intervention of the later explicit cognitive stages in the cognitive processing of individuals with ASD.

Although this study supports the hypothesis that the processing of gaze cues in individuals with ASD is atypical, there remain limitations in this study that should be addressed in future research. Participants selected for this study were younger adults with ASD because the chase detection paradigm requires higher attention and comprehension of participants. Children with ASD may be less likely to understand task requirements or able to maintain a longer period of concentration (Bröring et al., 2018; Dawson et al., 2004). Therefore, any conclusions based on this study may be limited to related phenomena in adults with ASD. Studies have shown that in TD individuals, the ability to estimate whether an object is social by motor cues appears early in infancy, but this ability is impaired in individuals with ASD (Klin & Jones, 2006; Träuble, Pauen, & Poulin-Dubois, 2014; Weisberg et al., 2014). The abnormal performance of their social cognition may result from a severe lack of social information input at an early stage, leading to insufficient social information processing needed to promote the development of corresponding systems within the nervous system (Fischer, Koldewyn, Jiang, & Kanwisher, 2014; Unruh et al., 2016).

Future studies should be designed with more accessible and understandable experimental tasks to explore the causes of social cognitive abnormalities in children and adolescents with ASD, if possible, utilizing a developmental perspective. In addition, in this study, eye-tracker technology was used to record the subject's eye movements during the behavioral experiment. This method enabled us to distinguish their processing strategies at different phases of the task. Our findings show the value of eye movement technology in exploring dynamic interactive social processing-related problems of individuals with ASD. Using neurophysiological recording methods such as ERP and fMRI to further understand the neural mechanism and physiological activation of individuals with ASD may also be good ways to explore their processing of social information.

In conclusion, this study supports the hypothesis that the role of a variety of gaze cues in the chase detection process of individuals with ASD was significantly different from that of TD individuals. In contrast to TD participants, individuals with ASD utilize an atypical processing pattern, which makes it difficult for them to use social information contained in oriented gaze cues. This finding may provide a new perspective on theoretical hypotheses and improve our understanding of the social information processing in individuals with ASD in real life.

Declarations

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Author Contributions

Jia Liu: Conceptualization, Methodology, Software, Formal analysis, Resources, Data Curation and Writing - Original Draft.

Jinsheng Hu: Validation, Supervision, Investigation and Funding acquisition.

Songze Li , Qi Li: Conceptualization and Writing - Review & Editing.

Xiaoning Zhao , Ying Liu , Shuqing Liu: Lab assistant.

All authors reviewed the manuscript.

Declarations of interest:

none

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Figures

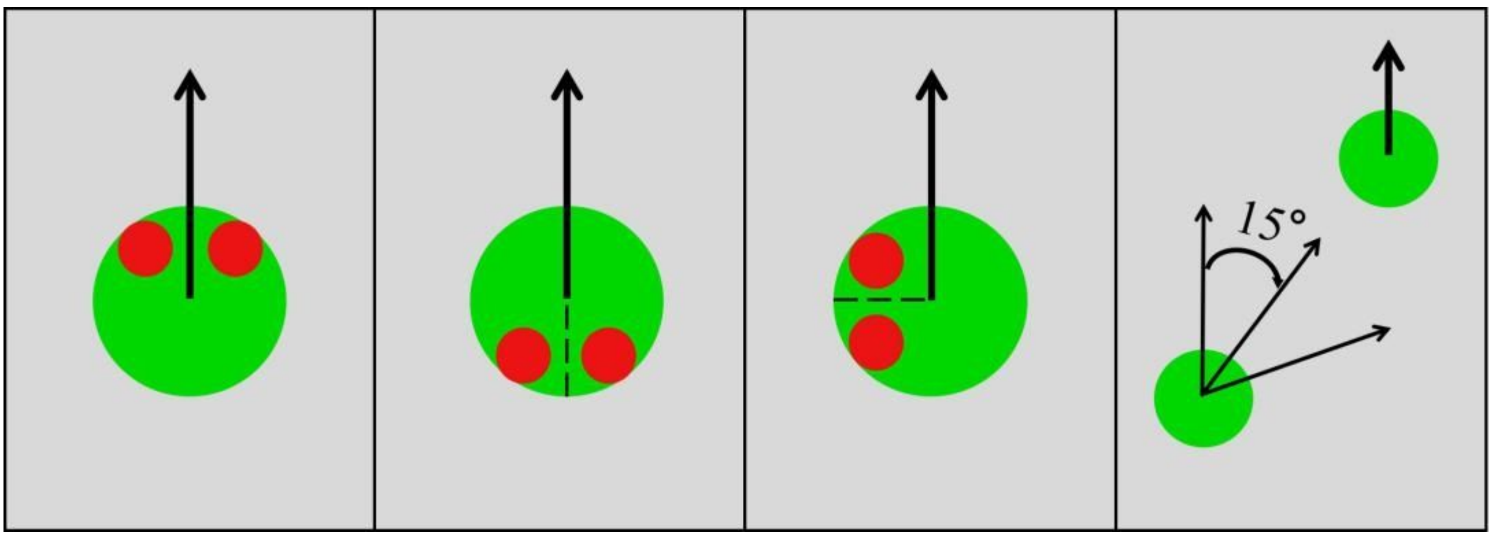

Figure 1

Illustration of the three cue conditions and chasing subtlety. The left image shows oriented cues, the center left one shows reverse cues, the center right image shows perpendicular cues, and the right image shows 15° chasing subtlety. The black arrows represent the direction of movement of the balls.

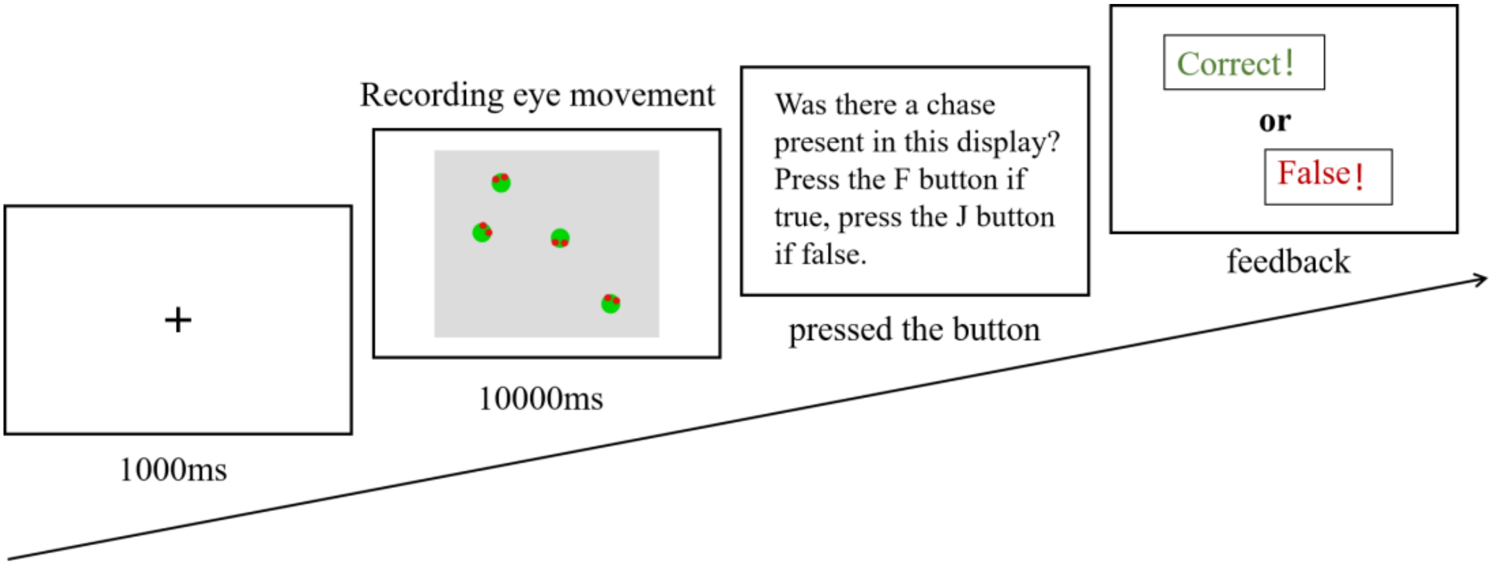

Figure 2

Graphical overview of the trial design.

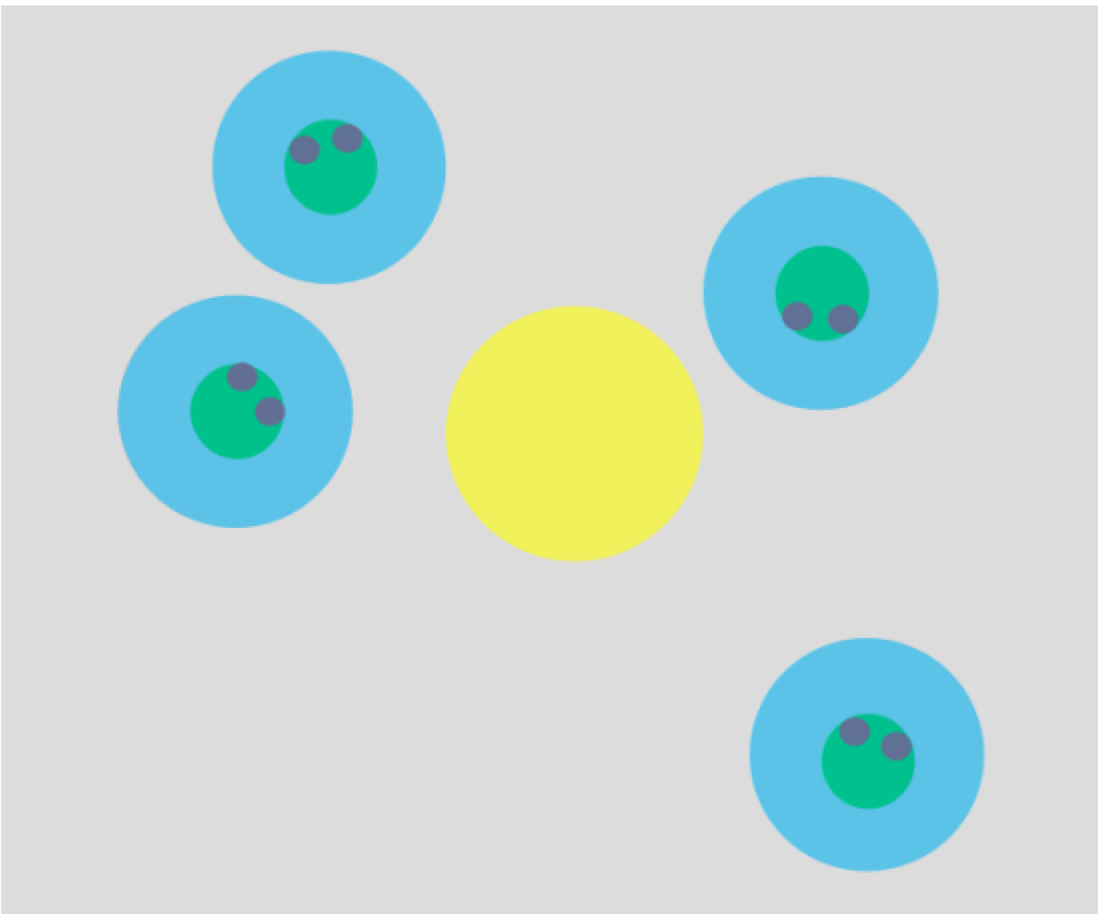

Figure 3

Samples of AOIs. The four blue areas were AOI1, which were located within 2.5 times the radius of every agent. The yellow area was AOI2, which was located within 2.5 times the radius of agent at the barycenter of 5 agents.

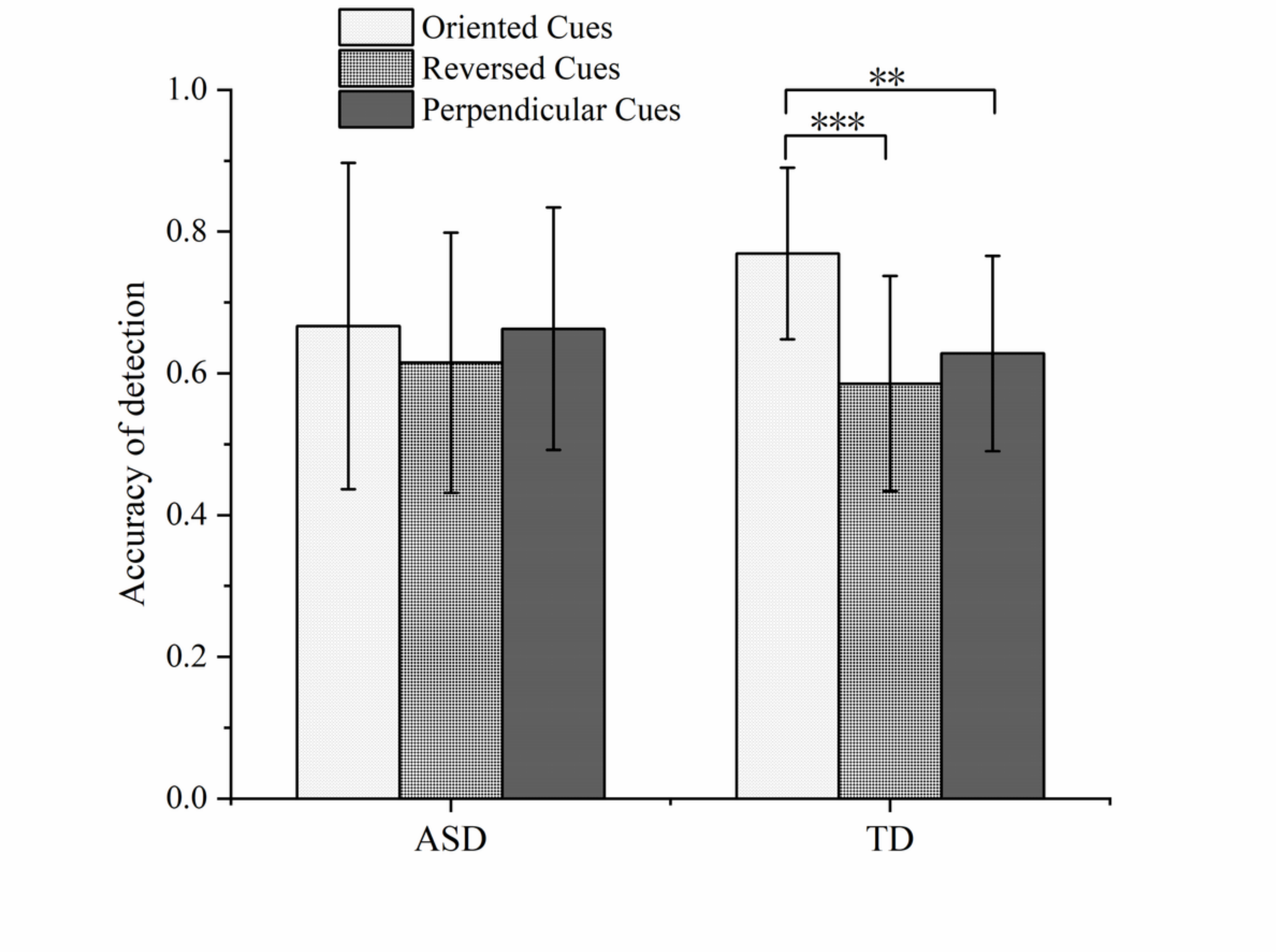

Figure 4

Accuracy of detection of the two groups in the 75° chase subtlety condition. Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. These symbols also apply to the figures below.

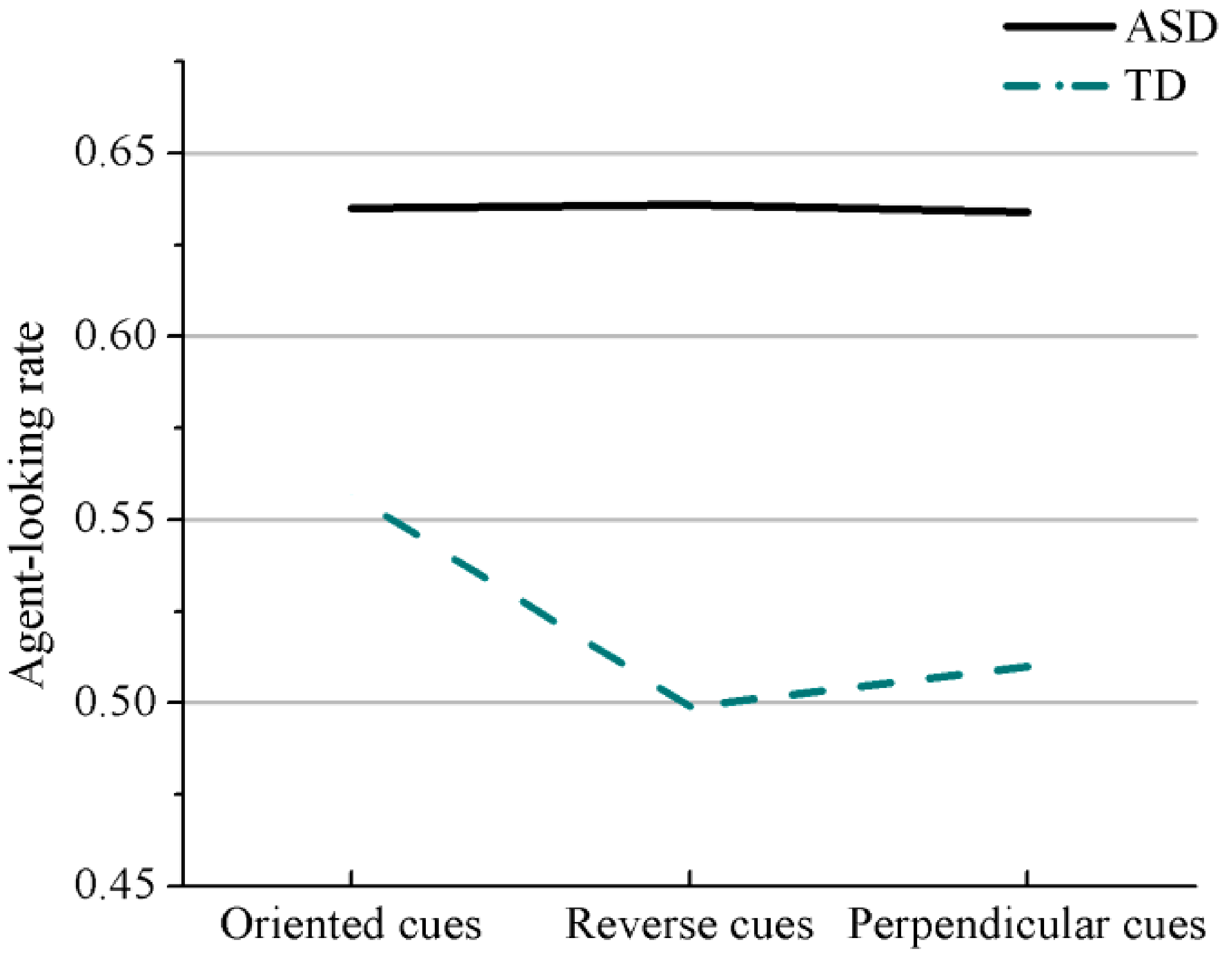

Figure 5

Agent-looking rate of the two groups in the three types of gaze cues

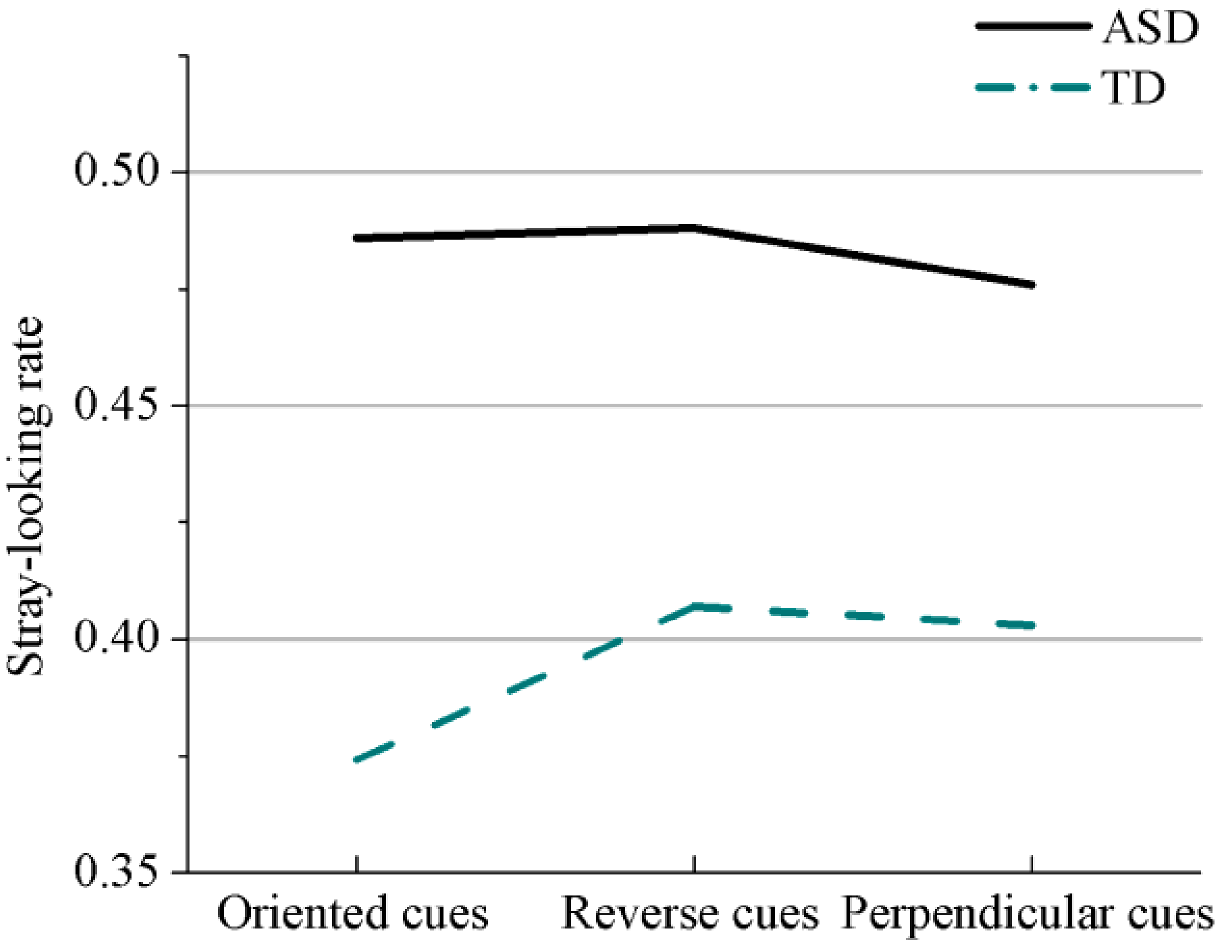

Figure 6

Stray-looking rate of the two groups in the three types of gaze cues

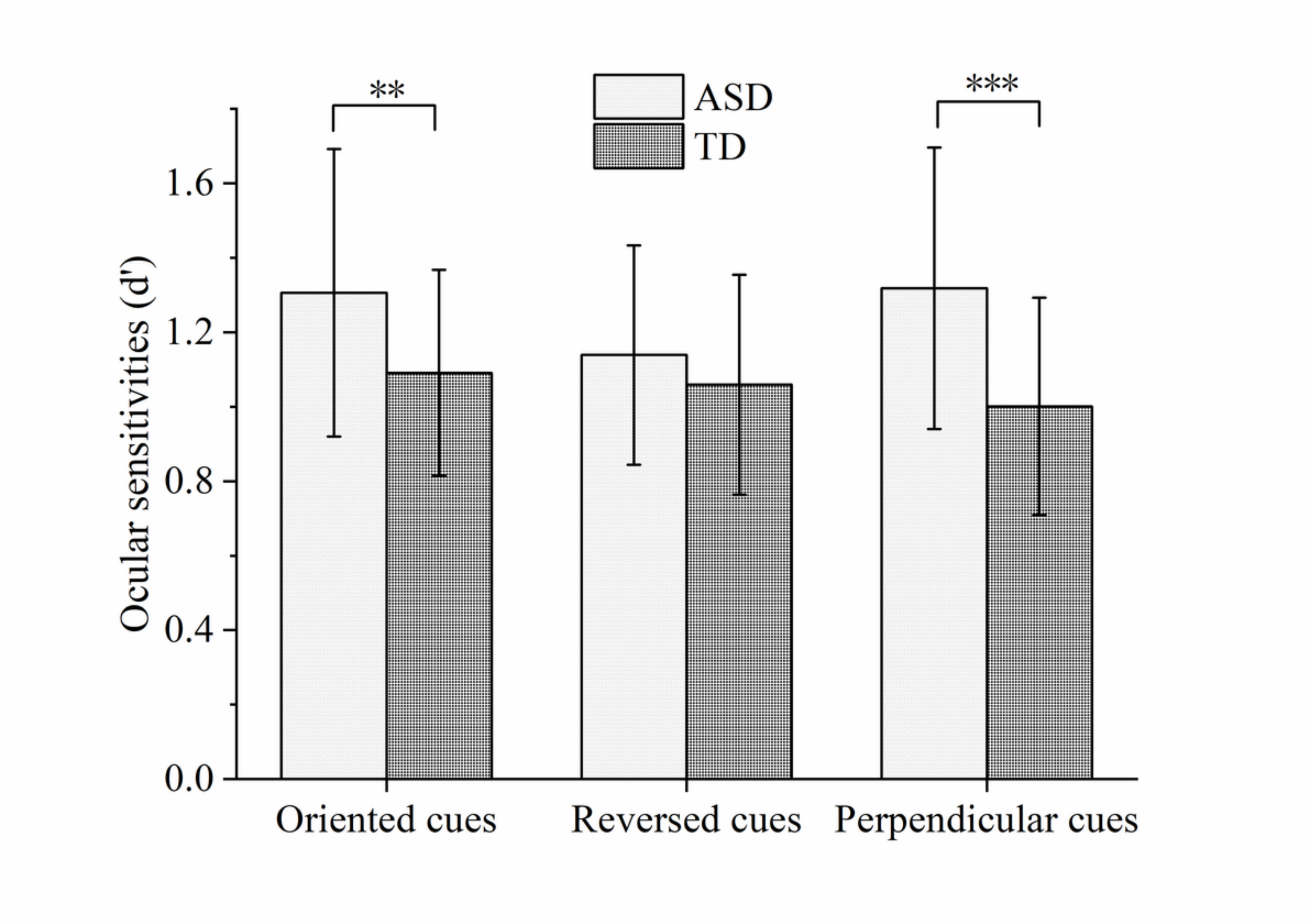

Figure 7

Ocular sensitivity of the two groups in the three types of gaze cues

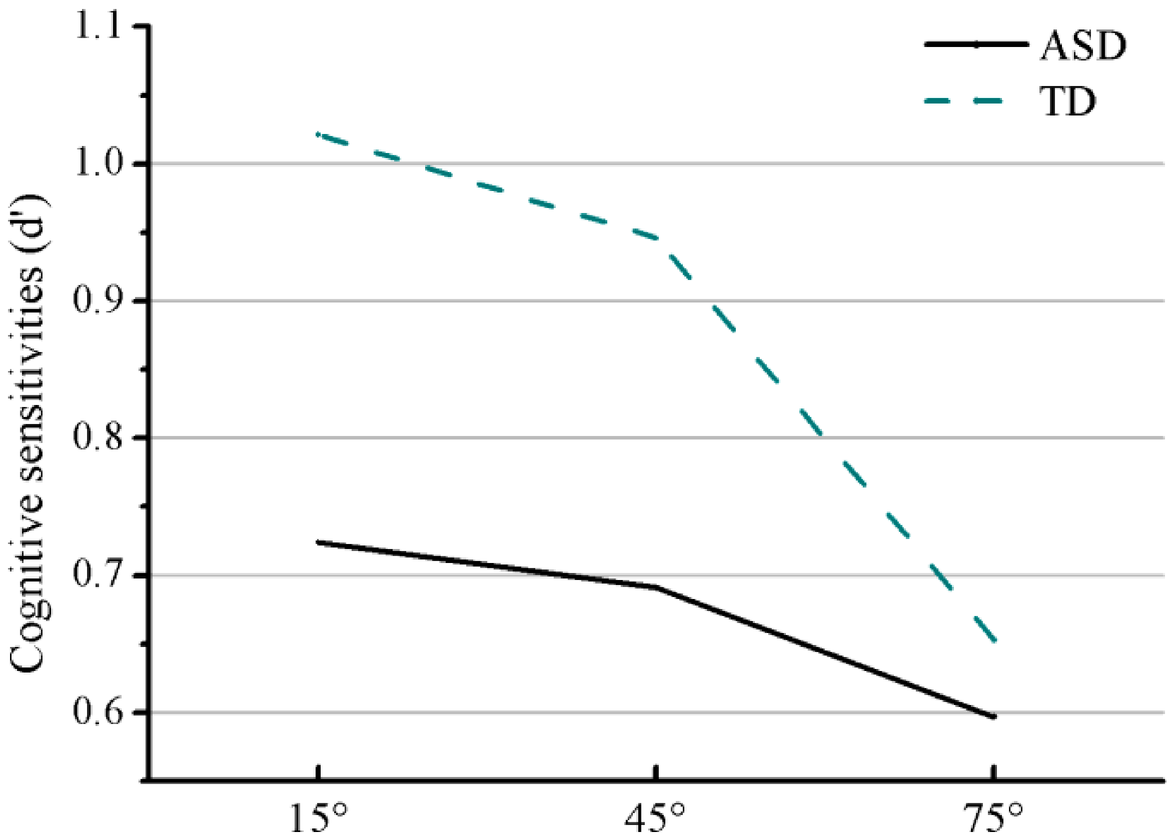

Figure 8

Cognitive sensitivity of the two groups in three chase subtlety conditions