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Qiandong Wang, Yixiao H , n i, Yaoxin ang, iao ing o , ng i, ang ang i Yi

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ORIGINAL PAPER

Children with Autism Spectrum Disorder Prefer Looking at Repetitive Movements in a Preferential Looking Paradigm

Qiandong Wang[1,2] · Yixiao Hu[3,4] · Dejun Shi[3,4] · Yaoxin Zhang[3,4] · Xiaobing Zou[5] · Sheng Li[3,4,6] · Fang Fang[1,3,4,6,7] · Li Yi[3,4]

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Abstract

ASD of sufficient social learning experiences and impacts their social interaction (Chevallier et al. 2012).

Unlike the abundance of research investigating atypical visual attention to social stimuli in ASD, the gaze abnormality relating to the other core symptom of ASD—the restricted interests and the repetitive behaviors—has attracted limited research attention (Baranek 2002). Many parents of children with ASD and clinicians reported that children with ASD show intensive visual attention to highly-specific objects (e.g., trains, computers, geographic figures, etc.), parts of objects, and repetitive movements (e.g., the rotating fan blades or car wheels) (Bodfish et al. 2000; Happé and Frith 2006; Lord et al. 1994; Pierce et al. 2011). Additionally, these unusual visual attention patterns have been included in the gold standard evaluation for ASD, Autism Diagnostic Interview-Revised (ADI-R; Lord et al. 1994) and Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2000). The visual preference for the repetitive behaviors related stimuli (RBRS) in ASD may serve as a reliable indicator of their repetitive behaviors (Lord et al. 2000; McCormick et al. 2014). Such a visual preference in ASD is hypothesized to act as a protective mechanism to relieve the tension caused by over-arousal when they face an overwhelming environment (Hutt et al. 1964; Sinha et al. 2014) or provide them with the rewarding sensory input when they experience low arousal levels (Lovaas et al. 1987; McCormick et al. 2014).

Reports from parents or clinicians, however, are inherently subjective, and objective methods need to be developed to assess these behaviors. Quantification of the repetitive behaviors in ASD is rarely done in the lab setting, due to the limited context to trigger the repetitive behaviors usually displayed in everyday life (Le Couteur et al. 2008; Ventola et al. 2006). To address this issue, some researchers have attempted to use preferential looking paradigms to explore the visual attention to RBRS in ASD by displaying RBRS and social stimuli simultaneously. By pairing dynamic geometric images with dynamic social images or pairing High Autism Interest Objects (HAIO, e.g., trains, computers) with faces, these studies found that children with ASD spent disproportionately more time scanning visual repetition (Pierce et al. 2011, 2016) and HAIOs (Sasson and Touchstone 2014) compared with typically developing (TD) children. It should be noted, however, that the above empirical research suffered from several limitations. First, in these studies, the RBRS were presented simultaneously with the social stimuli, so it is unclear whether the longer looking time spent on the RBRS in ASD reflects their preference for the repetitive movements/HAIOs or active avoidance of the social stimuli. Second, the stimuli used were not controlled for their low-level properties (e.g., color, shape, size and so on). Thus, it is also possible that the preference for the repetitive movements/HAIOs in ASD may reflect a group difference in preference for the low-level properties of the stimuli. Third, the preference for the repetitive movements in ASD was entangled with their preferences for certain objects (e.g., geometric images) in previous findings (Pierce et al. 2011, 2016). Thus, it is difficult to conclude whether children with ASD prefer looking at certain types of objects or the repetitive movements.

In the present study, we aimed to measure the visual preference for the repetitive movements in the early developmental course of ASD, using the preferential looking paradigm. To rule out the above alternative explanations in the previous results and to measure the visual preference for the repetitive movements in ASD more precisely, we employed two manipulations. First, we paired a repetitively moving object with a randomly moving object, instead of a moving social stimulus. Second, the repetitive moving objects and the randomly moving objects were identical (including the low-level properties) within each trial. Children with ASD and TD peers were presented with two types of movement patterns: a cartoon character moving in a repetitive way presented on one side of a computer screen, and the same character moving in a random route presented on the other side of the screen. We used an eye tracker to record children's eye movements to reveal their visual preferences for these two types of movements.

Based on the previous evidence, we hypothesized that children with ASD would show a visual preference for the repetitive movement pattern over the random movement pattern, whereas no preference might exist in TD children. This visual preference for the repetitive movements in ASD, if any, can thus only be explained by movement patterns (repetitive vs. random), instead of their tendency to avoid looking at the social stimuli or the difference between the two objects. In addition, to examine how this visual preference is related to the repetitive behaviors of ASD, we also correlated the degree of the repetitive visual preference to parent reported severity of repetitive behaviors.

Method

Participants

Participants were 20 young children with ASD ($M_{age}=3.73$ years, $SD_{age}=0.70$ years, range 2.74–5.24 years) and 20 young TD children ($M_{age}=3.98$ years, $SD_{age}=0.28$ years, range 3.55–4.66 years). We excluded one male child with ASD from the analyses due to his very low average screen-looking time (see "Data Analysis" section for details). Thus, the final sample consisted of 19 children with ASD ($M_{age}=3.79$, $SD_{age}=0.70$). There were no significant differences between the ASD and TD groups in chronological age, full scale IQ, and performance IQ, but the TD group

Table 1 Participants' characteristics

	ASD *M* (*SD*)	TD *M* (*SD*)	*t* value
N	19	20	N/A
Male (female)	19 (0)	17 (3)	N/A
Age (years)	3.73 (0.70)	3.98 (0.28)	− 1.53
FSIQ	82.37 (19.11)	89.30 (8.44)	− 1.45
Verbal IQ	73.00 (17.90)	84.10 (9.53)	− 2.43*
Performance IQ	90.53 (22.65)	97.10 (10.03)	− 1.16
RBS-R total	12.17 (7.28)	6.15 (5.25)	2.94*
Ritualistic/sameness	2.94 (2.21)	1.50 (1.73)	2.26*
Self-injurious	0.50 (1.04)	0.50 (1.15)	< 0.001
Stereotype	4.83 (3.20)	3.25 (2.71)	1.65
Compulsive	1.83 (1.79)	0.30 (0.66)	3.43*
Restricted	2.06 (1.86)	0.60 (1.05)	3.01*

FSIQ = Full Scale Intelligence Quotient; RBS-R = Repetitive Behavior Scale-Revised

*$p < 0.05$

***$p < 0.001$

had a higher verbal IQ than the ASD group (see Table 1 for details). The TD children were recruited from a typical kindergarten in Guangzhou, China, and the children with ASD were recruited from a clinic specialized for ASD in the same city. Diagnoses of ASD were confirmed by experienced clinicians to meet the criteria of ASD in the Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-V; American Psychiatric Association 2013). IQ was measured using the Chinese version of Wechsler Preschool and Primary Scale of Intelligence-Forth Edition (WPPSI-IV; Wechsler 2014), for 2.5- to 4-year-olds, and China-Wechsler Younger Children Scale of Intelligence (C-WYCSI; Gong 1988), for 4- to 6-year-olds. Detailed descriptions of participant characteristics can be found in Table 1.

The research was conducted according to the principles of the Declaration of Helsinki and was approved by the Ethical Committee of School of Psychological and Cognitive Sciences at Peking University. We obtained all of the children's oral consent and their parents' written consent before the experiment commenced.

Materials

The stimuli consisted of eight pairs of short cartoon videos (aspect ratio = 16:9, frame rate = 16 fps) featuring eight different characters. In each pair of cartoons, two identical characters moved in either the repetitive or the random pattern with the same speed and within the same moving space. Detailed descriptions of these videos can be found in the supplementary materials (see Table S1, available online).

We used Repetitive Behavior Scale-Revised (RBS-R; Bodfish et al. 2000) to measure repetitive behaviors of all children in the study[1]. The RBS-R is a 43-item questionnaire rated by children's caregivers on a four-point Likert scale from 0 ("behavior does not occur") to 3 ("behavior is a severe problem") based on the children's behaviors in the past month. Although the RBS-R originally contained six subscales, we chose to use the five-factor algorithm developed by Lam and Aman (Lam and Aman 2007), which was deemed more clinically meaningful and has been adopted by several studies aiming at investigating the repetitive behaviors in ASD (Joseph et al. 2013). The five factors were ritualistic/sameness behavior, stereotypic behavior, self-injurious behavior, compulsive behavior and restricted interests.

Procedure

Children were invited to sit approximately 60 cm away from a 24-inch LCD monitor (1440 × 900 pixels resolution) to watch cartoons freely. Eye movements were collected using a Tobii Pro X3-120 eye tracker (Tobiitech Technology, Stockholm, Sweden; sampling rate: 120 Hz). Before the experiment, children were asked to pass the calibration procedure of the Tobii five-point calibration program. The calibration was thought to be successful when both eyes achieved good mapping on all five test positions (smaller than 1 degrees of visual angle).

After the calibration procedure, the experiment began, including a total of eight trials. Before each trial, an attention-getter (a cartoon character from a popular Chinese animated television series) was presented on the center of the monitor to attract children's attention. The experimenter started each trial by pressing a space key when the child attended to the screen. During each trial, a pair of cartoons was presented simultaneously on the left and the right sides of the screen (Fig. 1). Each cartoon video subtended a visual angle of 12° × 6.75° to the children and lasted approximately 93 s on average. For each child, the order of the eight cartoon pairs was randomized, and the left/right placement of the repetitive and the random movements in each trial was counterbalanced. Eye tracking data was collected during the whole experiment.

Data Analysis

Fixations were defined based on I-VT fixation filter (Olsen 2012) with the following parameters settings: missing gaze data were filled in using linear interpolation, with a

[1] The scores of RBS-R were not available for one child with ASD and thus treated as missing data.

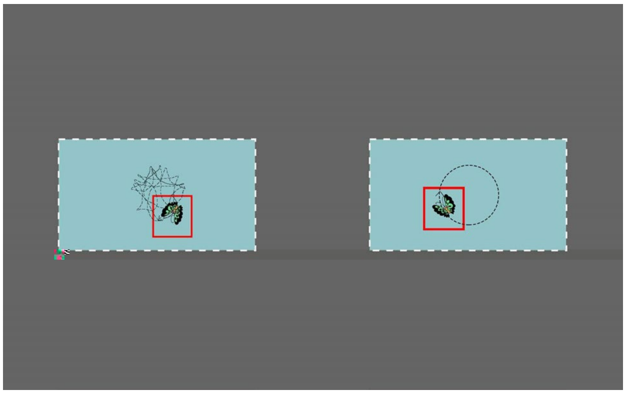

Fig. 1 A sample frame from one trial in the experiment. The left one is the random movement, and the right one is the repetitive movement. The dynamic AOIs are marked by the two red rectangles, representing the positions of the two moving characters and changing frame by frame depending on the locations of the characters. The static AOIs are marked by the two white rectangles with dashed lines bounding the videos and remained constant throughout each trial. The black dotted lines represent the moving routes

maximum gap length of 75 ms. Average gaze positions of the left and the right eyes were used to calculate fixations. The velocity threshold was set at 30°/s. Adjacent fixations were merged, with the maximum time between merged fixations set to 75 ms and the maximum angle between merged fixations set to 0.5°. Merging fixations close in time and space prevents longer fixations from being separated into shorter fixations because of data loss or noise. Finally, fixations shorter than 100 ms were discarded.

We first computed the proportional screen-looking time against the stimuli display duration. Like previous studies (e.g., Chawarska et al. 2016, 2012, 2013), trials with less than 25% proportional screen-looking time were considered invalid and excluded from the analysis. On average, in the ASD group, one trial was rejected per participant (*SD* = 1.56), whereas in the TD group, no trials were rejected. Furthermore, one child with ASD (male, 3.0-year-old, IQ = 84), whose average screen-looking time was lower than 25%, was also excluded from further analyses. It should be noted that when we included this child, the results were similar.

We defined two areas of interest (AOIs) for the two different moving patterns in each trial: the repetitive movement AOI and the random movement AOI (areas inside the red boxes in Fig. 1). These AOIs, called the dynamic AOIs, represented the positions of the two moving characters and changed frame by frame depending on the locations of the characters. By adding up the duration of all fixations falling inside each AOI in each trial, we obtained the total looking time on the repetitive and the random movements for each trial. Then, we computed the average proportional looking time on the repetitive AOI against the total looking time on both the repetitive and the random AOIs, defined as the dynamic repetitive preference index (RPI). A well above chance level (50%) RPI represents a looking preference for the repetitive movements over the random movements.

We also defined the static AOIs, which comprised the whole video scene (areas inside the white rectangles with dashed lines in Fig. 1). We then calculated the static RPI based on the static AOIs using similar methods as the dynamic RPI. We were able to evaluate the validity of the static RPI by correlating the static RPI with the more precise dynamic RPI based on the dynamic AOIs.

To examine when the repetitive preference appeared and how long it lasted, we also conducted a temporal course analysis of the RPI by dividing each trial into three phases (early, middle, and late phases, each phase lasting for approximately 31 s). Similarly, we calculated the RPIs for each phase and compared them with the chance (50%) and between groups.

We used *t*-tests and ANOVAs (both were two-tailed) to test our hypotheses and the false discovery rate (FDR) adjustment for multiple comparisons to control the type I error. Besides, we used the Pearson correlation to explore the potential associations between the RPI and children's age, IQ, and standardized measures of repetitive behaviors (RBS-R).

Results

Looking Time on the Screen

We first compared the total looking time on the screen between the ASD and the TD groups, and found that the ASD group ($M = 49.56$ s, $SD = 10.91$ s) dwelled significantly less on the screen than the TD group ($M = 59.80$ s, $SD = 8.89$ s), $t(37) = -3.22$, $p = 0.003$, Cohen's $d = 1.03$. We conducted a temporal course analysis for the screen-looking time in the early, middle, and late phases, and found that both group's screen-looking time declined across time, $F(2, 74) = 30.64$, $p < 0.001$, $\eta_p^2 = 0.453$ (Fig. 2). Simple effect analysis showed that the screen-looking time of both groups was significantly longer in the early phase than both in the middle and late phases, $ps < 0.001$, and no difference was found between the latter two phases, $ps > 0.05$.

Repetitive Preference Index Across the Total Time

As hypothesized, the ASD group showed a looking preference for the repetitive movements over the random movements with its RPI significantly higher than the chance level (50%) for both the dynamic AOI, $t(18) = 3.20$, $p = 0.005$, Cohen's $d = 0.73$, and the static

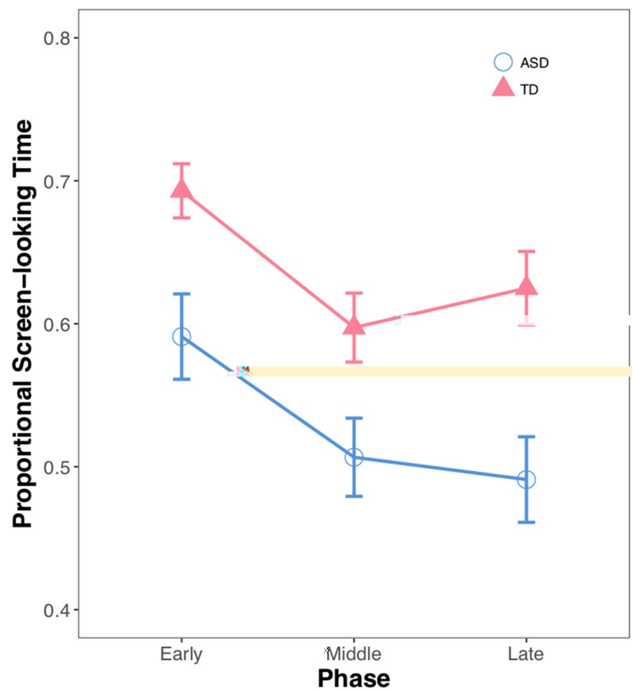

Fig. 2 Temporal course of the screen-looking time of the ASD and the TD groups in the early, the middle and the late phases based on the dynamic AOI (error bars denote standard errors)

AOI, $t(18)=4.18$, $p<0.001$, Cohen's $d=0.96$. The TD group did not show this preference compared to the chance level, $p>0.05$. The group comparisons further confirmed that the ASD group were more likely to show the looking preference for the repetitive movement compared with the TD group, $t(37)=3.07$, $p=0.004$, Cohen's $d=0.96$, and $t(37)=3.26$, $p=0.002$, Cohen's $d=1.02$, for the dynamic RPI and the static RPI respectively (Fig. 3). Since these two types of RPIs were highly correlated with each other ($r=0.93$, $p<0.001$), we only reported the results with the dynamic RPI in the following data analyses.

Considering that there were two different types of repetitive motions – the circular motion and straight-line motions in our stimuli (see Table S1 in the supplemental material). We further examined whether the RPI would differ between the two types of motions (circular vs. linear motions) by using a 2 (Motion Type) × 2 (Group) ANOVA on the RPI (Fig. 4). We found a significant effect of Motion Type, $F(1, 36)=14.73$, $p<0.001$, $\eta_p^2=0.29$, and Group, $F(1, 36)=5.78$, $p=0.021$, $\eta_p^2=0.14$, but no interaction between them, $F(1, 36)=0.10$, $p=0.751$, $\eta_p^2=0.003$. This finding indicated that both groups showed higher RPI to the stimuli moving in a circular pattern than in a linear pattern. However, the ASD group consistently showed higher RPI compared to the TD group, regardless of the type of motion.

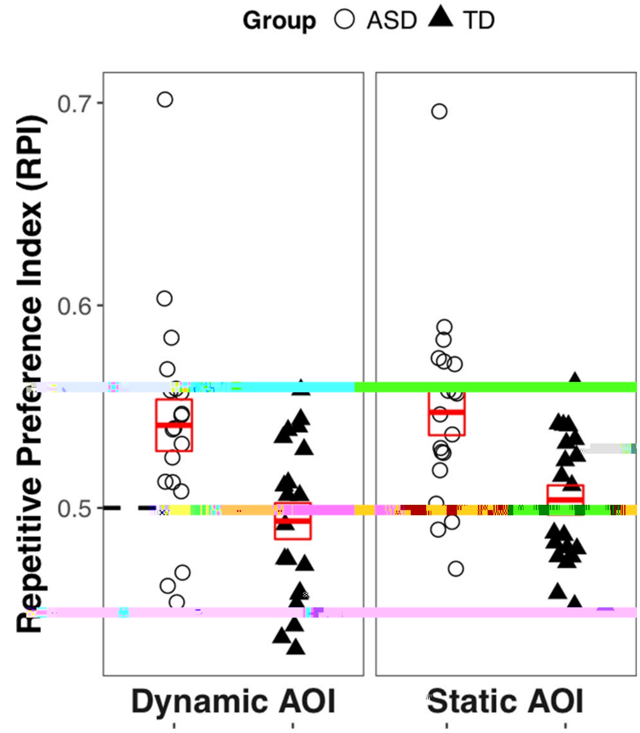

Fig. 3 Scatterplot of the repetitive preference index (RPI) of the ASD and the TD groups based on the dynamic and the static AOIs (the red middle lines in the box represent means; the size of the boxes denotes standard errors; the black dashed lines denote the 50% chance level)

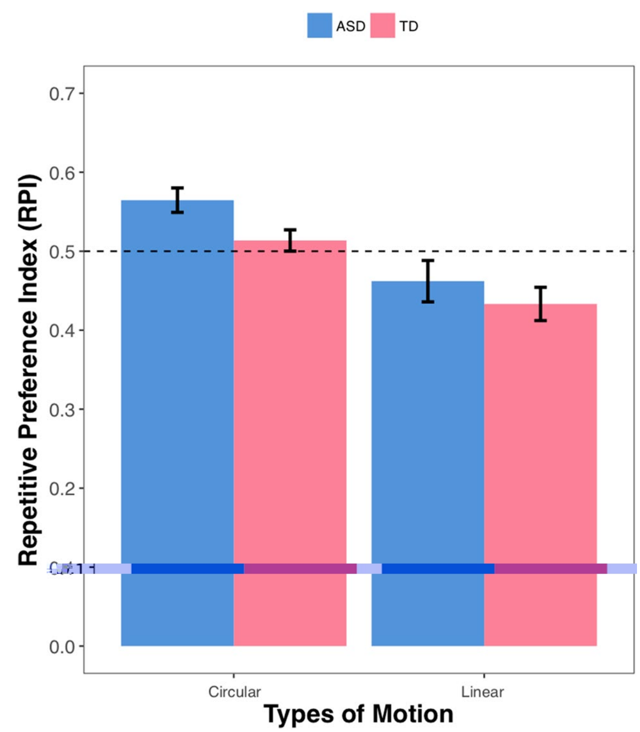

Fig. 4 Barplot of the repetitive preference index (RPI) of the ASD and the TD groups for different types of motions (circular vs. linear motions)

Temporal Course Analysis of the Repetitive Preference Index

The results of the temporal course analysis were shown in Fig. 5. When compared to chance (50%), the ASD group showed above-chance RPIs for all three phases, $t(18)=3.02$, $p=0.007$, Cohen's $d=0.69$; $t(18)=3.22$, $p=0.006$, Cohen's $d=0.74$; $t(18)=3.66$, $p=0.010$, Cohen's $d=0.75$, respectively, while the RPIs of the TD group did not differ from chance in any of the phases, $ps >$

(approximately four rounds in most cases), while the TD group shows no preference throughout the trial. (3) The RPI correlated significantly with the measures of the repetitive behaviors based on parent reports (RBS-R), especially the Restrict Interest subscale, suggesting that children with more severe repetitive behaviors had a higher preference for the repetitive movements. However, the RPI did not correlate with children's age and IQ.

Consistent with our findings, Pierce and colleagues also demonstrated that infants and toddlers with ASD spent more time fixating on the visual repetition than controls (Pierce et al. 2011, 2016). However, given that their findings can also be explained by the lack of interest or motivation in looking at the social stimuli or the preference for certain low-level properties or objects in ASD, it is hard to conclude that the repetitive preference in ASD was specific to the repetitive movements per se. In our study, by presenting children with the same moving objects simultaneously on the left and the right sides of the screen, the striking group differences found in the visual preference for the repetitive movements can be accounted for by the movement patterns (repetitive vs. random), which extends previous findings and suggests that children with ASD indeed prefer to look at the repetitive movements.

The visual preferences for the repetitive movements in ASD found in the current study could be explained by several accounts concerning its underlying mechanism. First, some researchers suggest that restricted interests and repetitive behaviors in ASD could naturally arise from their slower attentional disengagement or "sticky" attention (Fischer et al. 2014, 2015). One possibility is that children with ASD may show difficulty in disengaging from the repetitive stimulus once they have realized that this is a repetitive stimulus. Second, as social interaction is much more unpredictable for children with ASD than TD children according to the prediction theory of autism (Sinha et al. 2014), they may show less interest, motivation or even more aversion to the social interactions. Visual preferences for the repetitive movements in ASD may be a way to mitigate them from the unpredictable social world to a predictable world. Third, the hyper-systemizing theory of ASD proposes that individuals with ASD have an unusually strong drive to systemize, resulting in their preference for systems that change in highly predictable ways (Baron-Cohen 2008). Just as the hunger drive is stimulated by the need for food, the systemizing drive is stimulated by systematic patterns, and individuals with ASD may feel pleasure and satisfaction in finding such patterns. Last, McCormick and his colleagues suggested that the abnormal physiological arousal in ASD may underlie this visual preference (McCormick et al. 2014). In fact, both hyper- and hypo- arousal to sensory input have been reported in the literature among individuals with ASD (Ausderau et al. 2014; Lane et al. 2014). Repetitive behaviors are considered to provide self-regulating coping strategies to reduce anxiety in hyper-arousal or to increase sensory simulation in hypo-arousal (Leekam et al. 2011). Thus, just like the repetitive behaviors, the visual preference for the repetitive movements in ASD may serve as a coping strategy to reduce anxiety by blocking additional sensory input during high arousal (Hutt et al. 1964; McCormick et al. 2014; Sinha et al. 2014) or to provide rewarding sensory input when in low arousal (Hutt et al. 1964; Lovaas et al. 1987; McCormick et al. 2014; Sinha et al. 2014). According to the above hypotheses, although heightened visual preference for the repetitive movements may represent a unique phenomenon in ASD, its underlying causes can be much more complex (e.g., reduced arousal when experiencing hyper-arousal vs. increased arousal when experiencing hypo-arousal). Beyond our findings, future research is still required to explore the possible underlying causes for the repetitive movement preference effect in ASD. For example, we could explore the link between repetitive preference and arousal in children with ASD by recording skin conductance and eye movements simultaneously to identify the possible causes underlying the abnormal visual preference in ASD.

We also found some correlations between the RPI and the parent rep(e mo)22.10u1(een t)-8.t299(H(e be s). A)e coni.e.09999(ep measure obvious repetitive sensory motor behaviors and the insistence of sameness (e.g., Bishop et al. 2013; Gotham et al. 2007; South et al. 2005). However, owing to the difficulty in triggering the repetitive behaviors in the lab setting and the limited observation time during the administration of the ADOS (Le Couteur et al. 2008; Ventola et al. 2006), a more comprehensive evaluation of the RRB should combined the clinical observations and the parental reports (e.g., ADI-R or RBS; Großekathöfer et al. 2017; Leekam et al. 2011). However, the method of parent reports has been developmental trajectory of repetitive preference in children with ASD.

Given that the eye-movement results based on the static AOIs and the dynamic AOIs are highly correlated with each other, it is fairly reasonable to use the static AOIs in future studies to simplify the data collection and analyses. In the case of recording individuals' gaze to the left or the right side of the screen, the eye-tracking device could be replaced by a video camera, which requires no calibrations. This is highly advantageous for studies involving infants, who would have difficulty attending to an eye tracker and have difficulties regarding the calibration of eye-movement. Also, static AOIs, which are consistent across frames, may largely simplify the data analysis compared with the dynamic AOIs, which change across frames.

In conclusion, using the preferential looking paradigm, we found that a visual preference for the repetitive movements over the random movements in children with ASD, but not in TD children. Furthermore, the degree of this repetitive preference was directly related to the severity of repetitive behaviors based on parent reports. These findings not only reveal the atypical visual attention patterns of ASD beyond the previously found social attention abnormality, but also imply the feasibility of using preferential looking as a potential indicator for measuring repetitive behaviors to support the early screening of ASD in future investigations. Future research is needed to investigate the mechanism underlying this visual preference for repetitive movements.

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Author contributions LY, QW, BZ, SL, and FF conceived the study and created stimuli. YH and YZ carried out the testing. DS and QW formally analyzed the data and created the visualization of the data. QW, DS, YH, and LY drafted the manuscript. All authors reviewed the manuscript and gave final approval for publication.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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