Journal of Autism and Developmental Disorders
https://doi.org/10.1007/s10803-018-3546-5

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]

Abstract

The present study aimed to investigate the visual preference for repetitive movements in children with autism spectrum disorder (ASD). Young children with ASD and typically-developing (TD) children were presented simultaneously with cartoons depicting repetitive and random movements respectively, while their eye-movements were recorded. We found that: (1) the children with ASD spent more time fixating on the repetitive movements than the random movements, whereas the TD children showed no preference for either type of movements; (2) the children's preference for the repetitive movements was correlated with the parent reports of their repetitive behaviors. Our findings show a promise in using the preferential looking as a potential indicator for the repetitive behaviors and aiding early screening of ASD in future investigations.

Keywords Autism spectrum disorder · Repetitive behavior · Visual repetitive movement · Eye movement · Visual preference

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by social communication deficits, as well as the presence of restricted interests and repetitive behaviors (Lai et al. 2013). Associated with their social communication deficits, abnormal social attention has been extensively reported in the previous literature (Frazier et al. 2017; Klin et al. 2009; Pelphrey et al. 2002; Pierce et al. 2016; Sasson et al. 2008). Specifically, individuals with ASD exhibit reduced attention to others' faces and eyes (Chawarska et al. 2013; Frazier et al. 2017; Tanaka and Sung 2016), and biological motion (Klin et al. 2009), whereas they display abnormal visual preference for non-social objects (Chawarska et al. 2013; Pierce et al. 2011, 2016; Sasson and Touchstone 2014). These abnormal visual attention patterns have been found in adults (Dalton et al. 2005; Pelphrey et al. 2002; Yi et al. 2014), children (Chawarska et al. 2009; Yi et al. 2014), and even in infants (Chawarska et al. 2013; Jones and Klin 2013), suggesting that social attentional impairments are inherent and persistent problems in individuals with ASD. The reduced attention to social information in ASD is believed to be due to their diminished social motivation in early life, which deprives children with

---

Qiandong Wang, Yixiao Hu, and Dejun Shi have contributed equally to this work.

Electronic Supplementary Material The online version of this article (https://doi.org/10.1007/s10803-018-3546-5) contains supplementary material, which is available to authorized users.

✉ Li Yi
yilipku@pku.edu.cn

1 Peking-Tsinghua Center for Life Sciences, Peking University, Beijing, China

2 Academy for Advanced Interdisciplinary Studies, Peking University, Beijing, China

3 School of Psychological and Cognitive Sciences, Peking University, Beijing, China

4 Beijing Key Laboratory of Behavior and Mental Health, Peking University, 5 Yiheyuan Road, Beijing 100871, China

5 The Third Affiliated Hospital of Sun Yat-sen University, Guangzhou, China

6 PKU-IDG/McGovern Institute for Brain Research, Peking University, Beijing, China

7 Key Laboratory of Machine Perception (Ministry of Education), Peking University, Beijing, China

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.

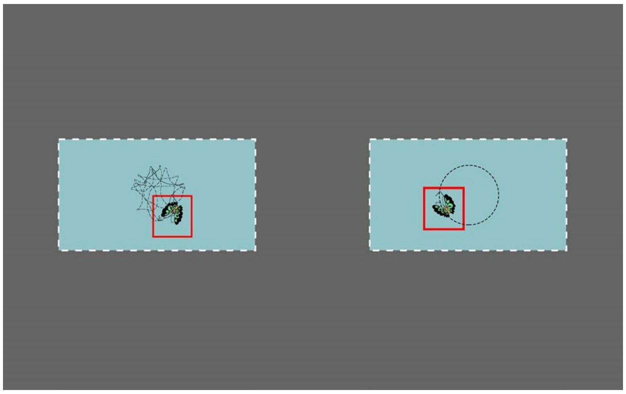

Fig. 1 A sample frame from one trial in the experiment. The left one is the random movement, and the right one is the repetitive movement. The dynamic AOIs are marked by the two red rectangles, representing the positions of the two moving characters and changing frame by frame depending on the locations 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

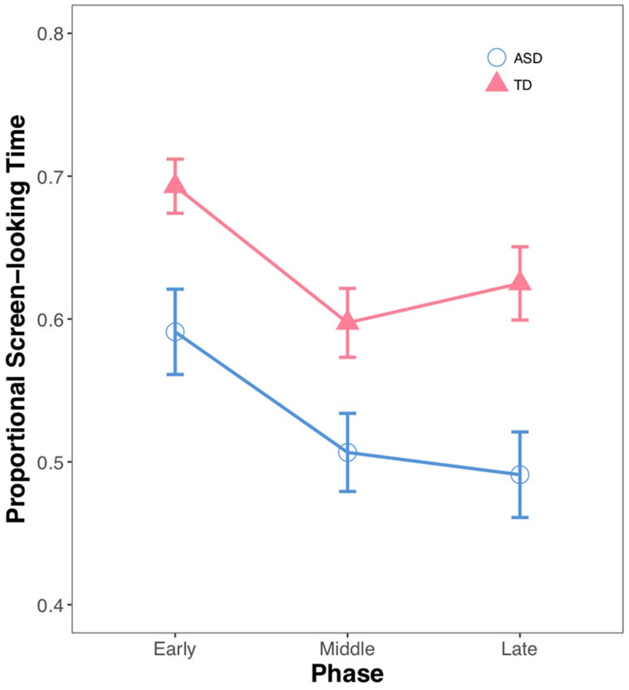

Fig. 2 Temporal course of the screen-looking time of the ASD and the TD groups in the early, the middle and the late phases based on the dynamic AOI (error bars denote standard errors)

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.

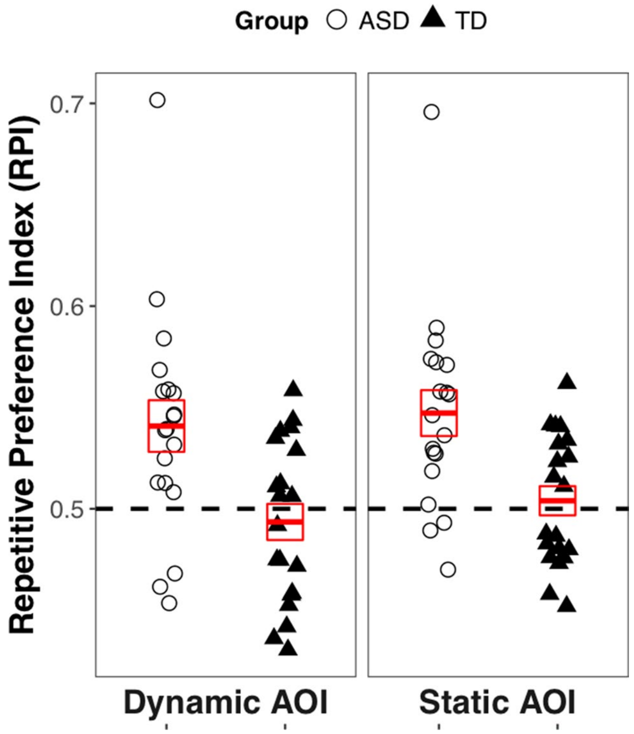

Fig. 3 Scatterplot of the repetitive preference index (RPI) of the ASD and the TD groups based on the dynamic and the static AOIs (the red middle lines in the box represent means; the size of the boxes denotes standard errors; the black dashed lines denote the 50% chance level)

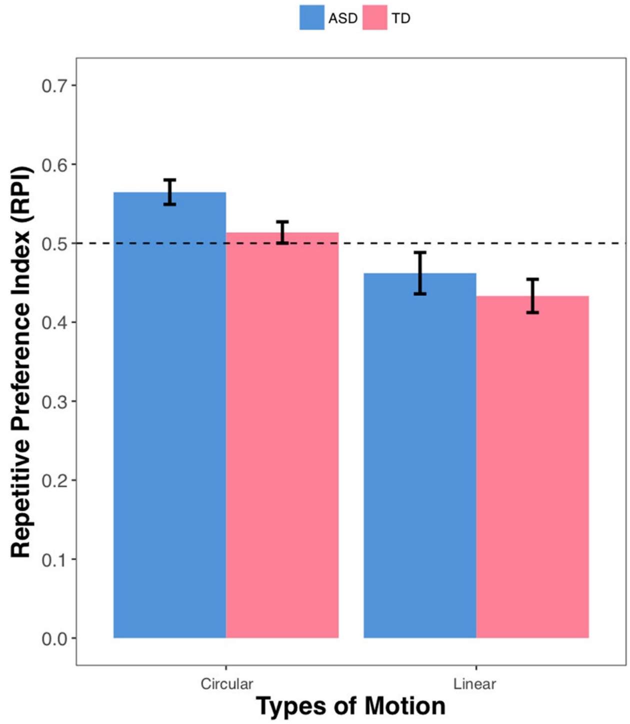

Fig. 4 Barplot of the repetitive preference index (RPI) of the ASD and the TD groups for different types of motions (circular vs. linear motions)

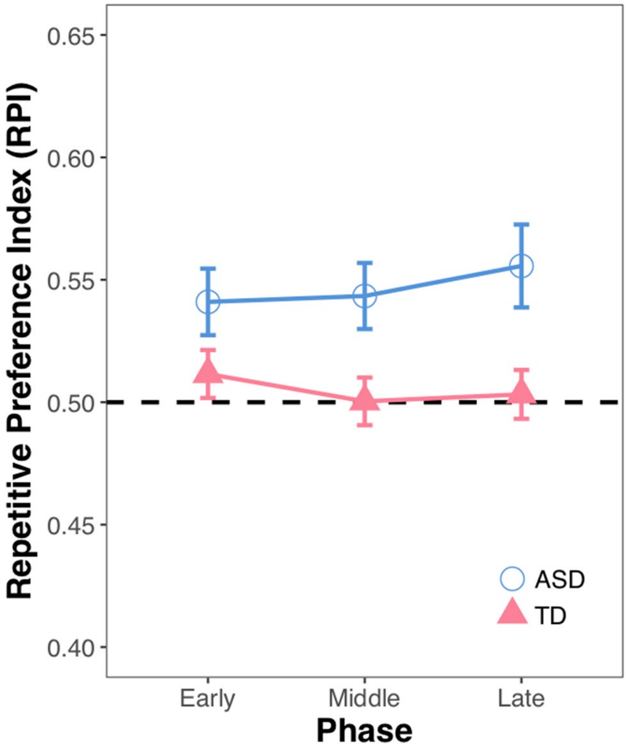

Fig. 5 Temporal course of the repetitive preference index (RPI) of the ASD and the TD groups in the early, the middle and the late phases based on the dynamic AOI (error bars denote standard errors; black dashed line denotes the 50% chance level)

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, $ps>0.05$. Furthermore, the 2 (Group) × 3 (Phase) repeated measures ANOVA on the RPI revealed that only the main effect of Group was significant, $F(1, 37)=11.45$, $p=0.002$, $\eta_p^2 = 0.24$. Particularly, the RPI of the ASD group marginally diverged from that of the TD group in the early phase, $t(37)=1.77$, $p=0.080$, Cohen's $d=0.56$. The divergence became significant in the middle and the late phases, $t(37)=2.61$, $p=0.020$, Cohen's $d=0.82$, and $t(37)=2.70$, $p=0.030$, Cohen's $d=0.85$, respectively.

Table 2 Correlations of the dynamic RPI with the scores of RBS-R, age, and IQ

	dynRPI		
	Two groups combined	ASD	TD
RBS-R total	0.287	0.442	−0.313
Stereotype	0.114	0.191	−0.246
Self-injurious	0.065	0.377	−0.191
Compulsive	0.358*	0.353	−0.255
Ritualistic/sameness	0.120	0.185	−0.336
Restricted	0.467**	0.570*	−0.006
Full scale IQ	−0.073	0.141	−0.235
Verbal IQ	0.025	0.317	0.047
Performance IQ	−0.140	0.062	−0.384
Age	−0.059	0.081	0.081

*$p<0.05$

**$p<0.01$

Correlations Between the RPI and Age, IQ, Scores of RBS-R

We tested the correlations between the RPI and the RBS-R scores for the ASD group and the TD group separately, and for both groups combined. One outlier from the ASD group was identified (based on 'outlierTest' function from 'car' package in R software) and excluded before the correlation analysis. When the two groups were considered together, the RPI was positively correlated with the Restricted Interests subscale and Compulsive subscale scores, $r=0.467$, $p=0.004$ and $r=0.358$, $p=0.030$ respectively. For the ASD group alone, the correlation between the RPI and RBS-R total scores approached significant, $r=0.442$, $p=0.076$, and the RPI was found to correlate positively with the Restricted Interests subscale scores ($r=0.570$, $p=0.017$). For the TD group, no correlations were found. Last, the RPI was not related to either age or IQ (the full-scale IQ and the IQ subscales). See Table 2 for detailed results.

Discussion

Using the preferential looking paradigm, the present study revealed the visual preference for the repetitive movements over the random movements in young children with ASD. Specifically, we found that: (1) children with ASD spent significantly more time attending to the repetitive movements compared to the random movements, whereas the TD children showed no preference for either type of movement, as indicated by their respective RPIs. (2) Our temporal course analysis further revealed that, the ASD group showed preference for the repetitive movements as early as the first 30 s (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 reported repetitive behavior scores (i.e., RBS-R) in our sample. Specifically, the RPI was positively correlated with the Restricted Interests subscale and Compulsive subscale scores when two groups were combined. More importantly, the RPI was positively correlated with the RBS-R total scores at a marginal significant level for the ASD group. This marginal correlation was mainly driven by the correlation between the RPI and the Restricted Interest subscale of the RBS-R. The restricted interest was defined as the strong attachment or preoccupation of unusual objects according to DSM-5 (American Psychiatric Association 2013). It is considered by some researchers to include the preference and preoccupation of objects with repetitive movements (e.g., clock and fan; Bodfish et al. 2000; Lam and Aman 2007), and playing in repetitive manners (e.g., repetitive rolling of a toy car or spinning of its wheels; Warsof 2013). Our results suggested that the RPI may specifically tap the restricted interest of the RRB in ASD. However, considering the relatively small sample size of our study, more future work is still needed to verify the relations between the preferences for the repetitive movements and the restricted interest in ASD. Moreover, a longitudinal design in the future studies could also help to identify what types of the RRB in older children are most linked to the early visual preference of the repetitive movements, and to test the convergent and discriminant validity of RPI.

The relation between RPI and RBS-R implied that the looking preference for the repetitive movements could be an indicator of some aspects of the repetitive behaviors in ASD. The clinical observation (e.g., ADOS) is sensitive to 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 questioned to be too subjective and influenced by inherent response bias (Möricke et al. 2016). Furthermore, the parents' observations of children's repetitive behaviors are such a cumulative process that it may take a long time to come to a conclusion about the existence of the repetitive behaviors (Moore and Goodson 2003). Our approach using the preferential looking paradigm has several advantages compared to the traditional methods based on clinical observations and parent reports for the purpose of measuring the repetitive behaviors in ASD. First, it may offer an efficient (only taking about 15 min) and an objective method for empirically quantifying the repetitive behaviors in ASD. Second, the repetitive behaviors should be more detectable by the preferential looking paradigm than the clinical observations of face-to-face interactions. Third, the simple passive viewing task used in our study allows researchers to test individuals with more severe ASD symptoms who are usually excluded from ASD research, thus providing a more comprehensive picture of visual attention patterns across the spectrum. Fourth, which is even more important, our task may be able to detect the presence of early abnormality in visual attention associated with the repetitive behaviors in infants at risk for ASD, who have not yet exhibited repetitive motor stereotypies that are noticeable to parents and clinicians. Future studies with infants at risk for ASD need to examine the feasibility of using the RPI as a potential biomarker for early screening of ASD. However, a more comprehensive ASD screening should combine the RPI with tasks measuring social attention (Klin et al. 2015) to improve the accuracy of detecting infants at risk of ASD.

Despite the above merit, the current approach has several constraints that should be considered with caution. Besides, the current preliminary exploration of the repetitive preference of ASD could provide insight into the design of the screen tool of RRB. First, it is noteworthy that some children, especially children with ASD, showed very low level of the attention to the screen overall. The loss of eye tracking data could be due to the blinks or inattention. Invalid trials and the excluded participant were all in the ASD group, probably due to their lower compliance and patience as well as lack of attention in completing the task. Children's looking time on the screen declined across time, which suggests that the presentation time (90 s) could be too long to watch such tedious and slow-paced videos without any scenarios. Based on our finding and previous studies (Pierce et al. 2011), we suggest that the presentation time of such tasks should be shorten to within 60 s to maintain children's attention in the future studies. More attractive designs of the cartoons are also suggested for the future research. Also, although the passive viewing task could be appropriate for infants, for older children, some tasks should be adopted (e.g., asking them to describe what happens in the videos later) to keep them alert during the task. Second, children's RPI were dependent not only on their repetitive behavior scores, but also on the characteristics of the stimuli. For example, the type of motion (circular vs. linear motions) could influence the RPI. The random movements in the linear-moving trials are not as random as circular-moving ones by design: although the objects in these random trials could start or end at a random location, their routes are still in repetitive patterns (e.g., going back and forth, and jumping up and down). Therefore, the random and the repetitive movements in these trials are more similar than other conditions, and this is supported by our findings that the circular motion is more salient than the linear motion for children with ASD to show the repetitive preference. Therefore, future studies should use stimuli with circular, not the linear motions in order to yield the largest effect size. Other factors, such as the color, size, and shape of the moving objects, should also be controlled to maintain an adequate internal consistency of RPI, which is an important issue to be considered for developing a standardized measurement or screening tool of the repetitive preference in ASD. Third, the use of typical controls in our study makes it difficult to determine whether repetitive movement preference effects are due to ASD per se or developmental disability more generally. Future research needs to consider the specificity of the repetitive movement preference to ASD by involving participants with other related mental disorders, such as individuals with obsessive–compulsive disorder, who are reported to display similar repetitive behaviors (Leekam et al. 2011). Fourth, we did not mesure the social communication abilities in our sample. The lack of discriminant validity using either clinician rated or parent questionnaires that tap social communication abilities should be addressed in the future study. Last, the participant sample in our study was made up exclusively of young children ranging in age from 2- to 5-years-old. This restricted age range could account for the lack of correlation between RPI and children's age. The developmental literature suggests that the repetitive behaviors in ASD continue to change with age, such as the insistence on sameness started mild and gradually became more severe for the children with ASD from 2 to 9 years (Richler et al. 2010). Future investigations that include children with broader age ranges or longitudinally track the development of the repetitive preference could provide insight into the 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.

Acknowledgements This study was supported by National Natural Science Foundation of China (31571135, 31470974) and Beijing Municipal Science & Technology Commission (Z171100000117015). The authors are grateful to Xiaoyan Chen, Jiayun Guo, Yifang Weng, Sinong Chen, Dr. Lisa Joseph, Dr. Junhao Pan, Tianbi Li, and staff in the Third Affiliated Hospital in Sun Yat-sen University, and children and parents who participated in our study.

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.

References

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th edn.). Washington, DC: American Psychiatric Association.

Baranek, G. T. (2002). Efficacy of sensory and motor interventions for children with autism. *Journal of Autism and Developmental Disorders, 32*(5), 397–422. https://doi.org/10.1023/A:1020541906063.

Baron-Cohen, S. (2008). Autism, hypersystemizing, and truth. *The Quarterly Journal of Experimental Psychology, 61*(1), 64–75. https://doi.org/10.1080/17470210701508749.

Bishop, S. L., Hus, V., Duncan, A., Huerta, M., Gotham, K., Pickles, A., Kreiger, A., Buja, A., Lund, S., & Lord, C. (2013). Subcategories of restricted and repetitive behaviors in children with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 43*(6), 1287–1297. https://doi.org/10.1007/s10803-012-1671-0.

Bodfish, J. W., Symons, F. J., Parker, D. E., & Lewis, M. H. (2000). Varieties of repetitive behavior in autism: Comparisons to mental retardation. *Journal of Autism and Developmental Disorders, 30*(3), 237–243. https://doi.org/10.1023/A:1005596502855.

Chawarska, K., Klin, A., Paul, R., Macari, S., & Volkmar, F. (2009). A prospective study of toddlers with ASD: Short-term diagnostic and cognitive outcomes. *Journal of Child Psychology and Psychiatry, 50*(10), 1235–1245. https://doi.org/10.1111/j.1469-7610.2009.02101.x.

Chawarska, K., Macari, S., Powell, K., DiNicola, L., & Shic, F. (2016). Enhanced social attention in female infant siblings at risk for autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 55*(3), 188–195. https://doi.org/10.1016/j.jaac.2015.11.016.

Chawarska, K., Macari, S., & Shic, F. (2012). Context modulates attention to social scenes in toddlers with autism. *Journal of Child Psychology and Psychiatry, 53*(8), 903–913. https://doi.org/10.1111/j.1469-7610.2012.02538.x.

Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological Psychiatry, 74*(3), 195–203. https://doi.org/10.1016/j.biopsych.2012.11.022.

Chawarska, K., Ye, S., Shic, F., & Chen, L. (2016). Multilevel differences in spontaneous social attention in toddlers with autism spectrum disorder. *Child Development, 87*(2), 543–557. https://doi.org/10.1111/cdev.12473.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences, 16*(4), 231–239. https://doi.org/10.1016/j.tics.2012.02.007.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., Alexander, A. L., & Davidson, R. J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience, 8*(4), 519–526. https://doi.org/10.1038/nn1421.

Fischer, J., Koldewyn, K., Jiang, Y. V., & Kanwisher, N. (2014). Unimpaired attentional disengagement and social orienting in children with autism. *Clinical Psychological Science, 2*(2), 214–223. https://doi.org/10.1177/2167702613496242.

Fischer, J., Smith, H., Pedraza, F. M., Carter, A. S., Kanwisher, N., & Kaldy, Z. (2015). Unimpaired attentional disengagement in toddlers with autism spectrum disorder. *Developmental Science, 19*(6), 1095–1103. https://doi.org/10.1111/desc.12386.

Frazier, T. W., Strauss, M., Klingemier, E. W., Zetzer, E. E., Hardan, A. Y., Eng, C., & Youngstrom, E. A. (2017). A meta-analysis of gaze differences to social and nonsocial information between individuals with and without autism. *Journal of the American Academy of Child & Adolescent Psychiatry, 56*(7), 546–555. https://doi.org/10.1016/j.jaac.2017.05.005.

Ausderau, K. K., Furlong, M., Sideris, J., Bulluck, J., Little, L. M., Watson, L. R., Boyd, B. A., Belger, A., Dickie, V. A., & Baranek, G. T. (2014). Sensory subtypes in children with autism spectrum disorder: Latent profile transition analysis using a national survey of sensory features. *Journal of Child Psychology and Psychiatry, 55*(8), 935–944. https://doi.org/10.1111/jcpp.12219.

Gong, Y. (1988). China-Wechsler younger children scale of intelligence (C-WYCSI). *Acta Psychologica Sinica, 20*(4), 30–42.

Gotham, K., Risi, S., Pickles, A., & Lord, C. (2007). The autism diagnostic observation schedule: Revised algorithms for improved diagnostic validity. *Journal of Autism and Developmental Disorders, 37*(4), 613–627. https://doi.org/10.1007/s10803-006-0280-1.

Großekathöfer, U., Manyakov, N. V., Mihajlović, V., Pandina, G., Skalkin, A., Ness, S., Bangerter, A., Goodwin, M. S. (2017). Automated detection of stereotypical motor movements in autism spectrum disorder using recurrence quantification analysis. *Frontiers in Neuroinformatics, 11*, 9. https://doi.org/10.3389/fninf.2017.00009.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*(1), 5–25. https://doi.org/10.1007/s10803-005-0039-0.

Hutt, C., Hutt, S. J., Lee, D., & Ounsted, C. (1964). Arousal and childhood autism. *Nature, 204*(4961), 908–909. https://doi.org/10.1038/204908a0.

Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2-6-month-old infants later diagnosed with autism. *Nature, 504*(7480), 427–431. https://doi.org/10.1038/nature12715.

Joseph, L., Thurm, A., Farmer, C., & Shumway, S. (2013). Repetitive behavior and restricted interests in young children with autism: Comparisons with controls and stability over 2 years. *Autism Research, 6*, 584–595. https://doi.org/10.1002/aur.1316.

Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature, 459*(7244), 257–261. https://doi.org/10.1038/nature07868.

Klin, A., Shultz, S., & Jones, W. (2015). Social visual engagement in infants and toddlers with autism: Early developmental transitions and a model of pathogenesis. *Neuroscience & Biobehavioral Reviews, 50*, 189–203. https://doi.org/10.1016/j.neubiorev.2014.10.006.

Lai, M. C., Lombardo, M. V., Chakrabarti, B., & Baron-Cohen, S. (2013). Subgrouping the autism "spectrum": Reflections on DSM-5. *PLOS Biology, 11*(4), e1001544. https://doi.org/10.1371/journal.pbio.1001544.

Lam, K. S. L., & Aman, M. G. (2007). The repetitive behavior scale-revised: Independent validation in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 37*(5), 855–866. https://doi.org/10.1007/s10803-006-0213-z.

Lane, A. E., Molloy, C. A., & Bishop, S. L. (2014). Classification of children with autism spectrum disorder by sensory subtype: A case for sensory-based phenotypes. *Autism Research, 7*(3), 322–333. https://doi.org/10.1002/aur.1368.

Le Couteur, A., Haden, G., Hammal, D., & McConachie, H. (2008). Diagnosing autism spectrum disorders in pre-school children using two standardised assessment instruments: The ADI-R and the ADOS. *Journal of Autism and Developmental Disorders, 38*(2), 362–372. https://doi.org/10.1007/s10803-007-0403-3.

Leekam, S. R., Prior, M. R., & Uljarevic, M. (2011). Restricted and repetitive behaviors in autism spectrum disorders: A review of research in the last decade. *Psychological Bulletin, 137*(4), 562–593. https://doi.org/10.1037/a0023341.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H. Jr., Leventhal, B. L., DiLavore, P. C., Pickles, A., Rutter, M. (2000). The autism diagnostic observation schedule-generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders, 30*(3), 205–223.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 24*(5), 659–685.

Lovaas, I., Newsom, C., & Hickman, C. (1987). Self-stimulatory behavior and perceptual reinforcement. *Journal of Applied Behavior Analysis, 20*(1), 45–68. https://doi.org/10.1901/jaba.1987.20-45.

McCormick, C., Hessl, D., Macari, S. L., Ozonoff, S., Green, C., & Rogers, S. J. (2014). Electrodermal and behavioral responses of children with autism spectrum disorders to sensory and repetitive stimuli. *Autism Research, 7*(4), 468–480. https://doi.org/10.1002/aur.1382.

Moore, V., & Goodson, S. (2003). How well does early diagnosis of autism stand the est of time? Follow-up study of children assessed for autism at age 2 and development of an early diagnostic service. *Autism, 7*(1), 47–63. https://doi.org/10.1177/1362361303007001005.

Möricke, E., Buitelaar, J. K., & Rommelse, N. N. (2016). Do we need multiple informants when assessing autistic traits? The degree of report Bias on offspring, self, and spouse ratings. *Journal of Autism and Developmental Disorders, 46*(1), 164–175. https://doi.org/10.1007/s10803-015-2562-y.

Olsen, A. (2012). The Tobii I-VT fixation filter. Algorithm description. Stockholm: Tobii Technology.

Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Paul, G., Goldman, B. D., & Piven, J. (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders, 32*(4), 249–261. https://doi.org/10.1023/A:1016374617369.

Pierce, K., Conant, D., Hazin, R., Stoner, R., & Desmond, J. (2011). Preference for geometric patterns early in life as a risk factor for autism. *Archives of General Psychiatry, 68*(1), 101–109. https://doi.org/10.1001/archgenpsychiatry.2010.113.

Pierce, K., Marinero, S., Hazin, R., McKenna, B., Barnes, C. C., & Malige, A. (2016). Eye tracking reveals abnormal visual preference for geometric images as an early biomarker of an autism spectrum disorder subtype associated with increased symptom severity. *Biological Psychiatry, 79*(8), 657–666. https://doi.org/10.1016/j.biopsych.2015.03.032.

Richler, J., Huerta, M., Bishop, S. L., & Lord, C. (2010). Developmental trajectories of restricted and repetitive behaviors and interests in children with autism spectrum disorders. *Development and psychopathology, 22*(1), 55–69. https://doi.org/10.1017/S0954579409990265.

Sasson, N. J., & Touchstone, E. W. (2014). Visual attention to competing social and object images by preschool children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 44*(3), 584–592. https://doi.org/10.1007/s10803-013-1910-z.

Sasson, N. J., Turner-Brown, L. M., Holtzclaw, T. N., Lam, K. S. L., & Bodfish, J. W. (2008). Children with autism demonstrate circumscribed attention during passive viewing of complex social and nonsocial picture arrays. *Autism Research, 1*(1), 31–42. https://doi.org/10.1002/aur.4.

Sinha, P., Kjelgaard, M. M., Gandhi, T. K., Tsourides, K., Cardinaux, A. L., Pantazis, D., Diamond, S. P., & Held, R. M. (2014). Autism as a disorder of prediction. *Proceedings of the National Academy of Sciences, 111*(42), 15220–15225. https://doi.org/10.1073/pnas.1416797111.

South, M., Ozonoff, S., & McMahon, W. (2005). Repetitive behavior profiles in asperger syndrome and high-functioning autism. *Journal of Autism and Developmental Disorders, 35*(2), 145–158. https://doi.org/10.1007/s10803-005-1992-3.

Tanaka, J. W., & Sung, A. (2016). The "eye avoidance" hypothesis of autism face processing. *Journal of Autism and Developmental Disorders, 46*(5), 1538–1552. https://doi.org/10.1007/s10803-013-1976-7.

Ventola, P. E., Kleinman, J., Pandey, J., Barton, M., Allen, S., Green, J., Robins, D., & Fein, D. (2006). Agreement among four diagnostic instruments for autism spectrum disorders in toddlers. *Journal of*

Autism and Developmental Disorders, 36(7), 839–847. https://doi.org/10.1007/s10803-006-0128-8.

Warsof, B. D. (2013). *Repetitive and restricted behaviors and interests in children and adolescents with autism spectrum disorder* (Doctoral dissertation, University of Virginia). Retrieved from https://search.proquest.com/docview/1435635245/previewPDF/5EA610D91A6648ACPQ/1?accountid=13151.

Wechsler, D. (2014). Wechsler Preschool and Primary Scale of Intelligence—Fourth CN Edition (WPPSI-IV CN). (Y. Li & Z. J, Trans. Y. Li & Z. J Eds.). King-May Company China.

Yi, L., Feng, C., Quinn, P. C., Ding, H. Y., Li, J., Liu, Y. B., & Lee, K. (2014). Do individuals with and without autism spectrum disorder scan faces differently? A new multi-method look at an existing controversy. *Autism Research, 7*(1), 72–83. https://doi.org/10.1002/aur.1340.