Journal of Cognitive Psychology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/pecp21

The impact of circumscribed interest distractors on attentional orienting in young children with autism: eye-tracking evidence from the remote distractor paradigm

Li Zhou, Fuyi Yang & Valerie Benson

To cite this article: Li Zhou, Fuyi Yang & Valerie Benson (22 Mar 2024): The impact of circumscribed interest distractors on attentional orienting in young children with autism: eye-tracking evidence from the remote distractor paradigm, Journal of Cognitive Psychology, DOI: 10.1080/20445911.2024.2331823

To link to this article: https://doi.org/10.1080/20445911.2024.2331823

Published online: 22 Mar 2024.

JOURNAL OF COGNITIVE PSYCHOLOGY
https://doi.org/10.1080/20445911.2024.2331823

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

The impact of circumscribed interest distractors on attentional orienting in young children with autism: eye-tracking evidence from the remote distractor paradigm

Li Zhou[a], Fuyi Yang[a] and Valerie Benson[b]

[a]Faculty of Education, East China Normal University, Shanghai, People's Republic of China; [b]School of Psychology and Humanities, University of Central Lancashire, Preston, UK

ABSTRACT
Studies from free-viewing tasks report that children with autism spectrum condition (ASC) exhibit an attentional bias for circumscribed interest (CI) objects (e.g., vehicles) over non-CI objects (e.g., furniture). This atypical preference has led researchers to hypothesise that ASC children would be more distracted by CI-related objects than non-CI-related objects. The current study aimed to explore this issue using a remote distractor paradigm. We found longer saccade latencies for centrally presented distractors in ASC, suggesting delayed endogenous disengagement. Additionally, higher error rates and fewer corrective saccades in ASC indicated poorer attentional control. Neither latencies nor errors were modulated by stimulus types but increased dwell time for CI-related objects over non-CI-related objects in ASC, demonstrated some support for the CI attentional bias reported in previous free-viewing studies. The findings are discussed in relation to how task demands in basic orienting paradigms might mask any CI-related preference bias in children with ASC.

ARTICLE HISTORY
Received 5 December 2023
Accepted 12 March 2024

KEYWORDS
Autism spectrum condition; circumscribed interests; attentional orienting; attentional control; remote distractor paradigm

In addition to the two core symptoms of autism spectrum condition (ASC), social communication and restricted repetitive behaviours and interests (RRBI; American Psychiatric Association, 2013), attentional challenges have commonly been reported during the developmental stages of individuals with ASC (Ames & Fletcher-Watson, 2010). Atypical social attention has been extensively explored and documented throughout the life spans of individuals who have autism, whereas limited research has focused on how the RRBI (non-social) features of ASC might impact the attentional domain (Wang et al., 2018; Yerys, 2015). In the non-social domain, children with ASC display a bias in attention for some objects like vehicles, helicopters, instruments and clocks (Sasson & Touchstone, 2014; South et al., 2005). This type of non-social stimuli belongs to the circumscribed interests (CI) feature of ASC, a notable subcategory of the restricted repetitive behaviours and interests profile included in the diagnostic criteria of ASC, whereby individuals with autism exhibit highly focused and restricted interests in specific CI-related objects (Ambarchi et al., 2023; Harrop et al., 2018). South et al. (2005) identified and classified CI into different categories. These include transportation vehicle (e.g. trains, planes), certain categories of toys (e.g. Lego®), electronic devices (e.g. home electronic devices, computer equipment), road signs, and sporting equipment. It has been observed that CI objects are highly salient and rewarding for individuals with ASC (Kohls et al., 2018), and the influence and intensity of these interests do not always improve with age (South et al., 2005). There is growing evidence to show that individuals with ASC spend a significant amount of time exploring, engaging, and collecting their preferred CI-related objects (see Harrop et al.,

CONTACT Valerie Benson vbenson3@uclan.ac.uk University of Central Lancashire, Fylde Road, Preston, Lancashire PR1 2HE, UK; Fuyi Yang fyyang@spe.ecnu.edu.cn East China Normal University, No. 3663 North Zhongshan Road, Shanghai 200062, People's Republic of China

2019 for a review). Therefore, it follows that this atypical behaviour may limit the ability to attend to and acquire relevant or salient social information, potentially interfering with the nature of social interactions (Sasson et al., 2008; Valiyamattam et al., 2023).

Eye-tracking studies have revealed that individuals with autism exhibit aberrant gaze patterns on CI-related items compared with typically developing (TD) counterparts (DiCriscio et al., 2016; Unruh et al., 2016; Zhou et al., 2022). For example, participants with autism show a detail-oriented (more fixation counts) and perseverative (longer fixation duration and more fixation proportion) processing manner on CI-related stimuli over non-CI-related stimuli (e.g. furniture, clothes, plants). By contrast, TD counterparts show less interest in either type of non-social objects, and instead behave more sensitively to social stimuli, e.g. faces (Unruh et al., 2016; Valiyamattam et al., 2023). Additionally, the presence of CI-related objects increased latencies and decreased fixation duration to social stimuli like faces in individuals with ASC (Sasson et al., 2008, 2012; Sasson & Touchstone, 2014; Unruh et al., 2016). However, the ASC group behaved similarly to TD peers in their eye-movement patterns to facial regions in stimuli when these items were presented with non-CI-related items (Sasson & Touchstone, 2014).

This atypical processing pattern observed for CI-related stimuli in children with autism has been shown to influence attentional orienting performance in visual orienting tasks. DiCriscio et al. (2016) found that children and teenagers with autism showed less cognitive control (more error rates) for CI-related objects in an anti-saccade task relative to TD peers. This effect was absent for non-social or facial stimuli presented in the same task. A further visual-orienting study reported that children with autism reacted faster to orient to CI-related lateral targets compared to both non-CI-related targets and facial targets (Mo et al., 2019). By contrast, TD children oriented faster towards faces compared to non-social stimuli (CI-related/non-CI-related objects). Additionally, a more recent study (Zhou et al., 2022) showed that young children with ASC had increased failure disengagement rates (a failure to orient to a target) in the presence of foveal CI-related stimuli over non-CI-related stimuli in a modified gap-overlap paradigm. Conversely, this difference was absent in TD children. Children in the TD group were able to shift their focus of attention swiftly from both CI-related and non-CI-related items to orient to the peripheral target region.

While several studies have investigated the influence of CI-related objects on attentional orienting, some specific limitations of this research need to be noted here. First, the above orienting studies introduced either CI-related or non-CI-related stimuli singularly presented in one single visual region, either solely in the foveal region (e.g. Zhou et al., 2022), or in the peripheral region (e.g. DiCriscio et al., 2016; Mo et al., 2019). Therefore, no comparisons can be made for the effects of central and parafoveal or peripheral stimuli when these are presented in the same experiment. In the real world, distractors may manifest at any location randomly, rather than being consistently presented in a fixed location. Furthermore, most studies have adopted passive viewing tasks with less cognitive control (e.g. preference-looking or visual search paradigms) to examine visual orienting patterns for CI-related or non-CI-related objects (e.g. Unruh et al., 2016; Valiyamattam et al., 2023). Those studies that have adopted lower-level visual orienting tasks like the gap-overlap paradigm have found that participants exhibited ceiling effects in failure to orient rate (e.g. Zhou et al., 2022). Hence, little is known about attentional orienting characteristics in the context of CI or non-CI under higher-level attentional demand tasks, which require cognitive control. Our perception goes beyond mere passive observation of external stimuli, and we need to be able to inhibit irrelevant distractors in the environment to allow us to engage with more meaningful content. Finally, the evidence from relevant research has concentrated on ASC adolescents or older ASC children, with limited investigations into younger children with autism (Lockwood Estrin et al., 2024; Zhang et al., 2020). It is well known that the presence of CI-related stimuli impacts voluntary orienting in ASC youth (DiCriscio et al., 2016), however, whether these CI-related items influence attentional orienting in young children with ASC or not has been understudied.

The current study aimed to measure attentional orienting in young children with and without ASC using eye-tracking technology by adopting a higher attentional level task, the remote distractor paradigm (RDP, Walker et al., 1997), under the context of both CI-related and non-CI-related distractors presented at different visual locations. The RDP encompasses four distractor sub-conditions: central (foveal) distractor (C), parafoveal distractor (NEAR), peripheral distractor (FAR), and no distractor (single target, ST) conditions. Participants are required to ignore irrelevant distractors appearing at various visual locations and look at the lateral targets. Therefore, children need to make an orienting response under greater cognitive control than that required in previous free-viewing tasks. Both involuntary automated orienting (saccade to distractors) and voluntary orienting (saccade to targets) were explored in the RDP. In the cases of an erroneous first saccade being made towards the distractor, the second saccades will be analysed to investigate if these are corrective saccades (re-orienting to the target location), a pivotal indicator to check that initial saccades reflect reflexive orienting that is then corrected with a voluntary response. This type of analysis has been overlooked in previous studies (e.g. Zhang et al., 2020), but it is very useful to highlight whether participants have understood the task initially unable to impose voluntary control over the reflexive orienting system. In addition, a further measure of dwell time (the time spent looking at a specific region) will be evaluated across both groups to explore whether, when participants looked at the distractors, there would be differences between CI-related and non-CI-related distractors for the two participant groups.

In light of prior evidence indicating differences in the development of cognitive control in young ASC children (Amestoy et al., 2021; Zhang et al., 2020), we hypothesised that children with autism would have lower attentional control, and would be more susceptible to interference during attentional orienting compared to TD children. This should be reflected in increased saccade latency (SL), increased saccade errors, and fewer corrective saccades in the ASC children. Moreover, given that CI-related objects impact ASC children's attention (Sasson et al., 2008; Valiyamattam et al., 2023), such stimuli might pose greater challenges in visual orienting within the context of CI in children with autism. Thus, the basic effects of increased latency and/or dwell time should also be modulated by CI-related distractors in ASC children.

Methods

Participants

A total of 61 participants took part in the current study. The sample included 29 young children with autism ($M_{age} = 66.83$ months) and 32 gender-, age- and IQ-matched TD children ($M_{age} = 70.08$ months). A power analysis was conducted using GPower 3.1 (Faul et al., 2007) to determine whether a sufficient number of participants were recruited for the current study. At least 24 participants were required for the RM-ANOVA with group (ASC, TD) designed as the between-group factor, and both distractor condition (ST, C, NEAR, FAR) and distractor type (CI, non-CI) were considered as within-group factors, using similar parameter settings (0.95 power, an alpha of 0.05, and 0.5 as correlations) as those reported in previous studies (Zhou et al., 2022).

The ASC children were recruited from an autistic research and service centre in Tianjin, and all TD children were recruited from two kindergartens in the same city. All ASC children received a formal diagnosis of ASC from more than one experienced clinical physician according to DSM-V standards (American Psychiatric Association, 2013). Parents or interventionists of all participants completed the Autism Spectrum Quotient: children's version (AQ; Auyeung et al., 2008) to confirm the diagnosis. As expected, significant differences in AQ scores were exhibited between the ASC group and the TD group ($t_{(59)} = 7.19$, $p < 0.001$). Additionally, the Wechsler Preschool and Primary Scale of Intelligence-Fourth Edition CN version (Wechsler, 2014) was employed to evaluate all children's verbal IQ, performance IQ and full-scale IQ. See Table 1 for detailed information on participant demographics.

Table 1. Demographic data of the ASC and TD groups (mean and SD).

	ASC ($n = 29$)	TD ($n = 32$)	χ^2/t	p
male/female	21/8	25/7	0.27	0.605
Age (months)	66.83 (10.47)	70.08 (3.41)	−1.66	0.102
VIQ	104.03 (12.65)	103.22 (9.39)	0.29	0.775
PIQ	114.45 (13.57)	108.97 (9.51)	1.84	0.071
FSIQ	109.35 (12.03)	105.78 (7.44)	1.41	0.165
AQ	76.07 (8.38)	55.31 (13.34)	7.19	< 0.001

Note: ASC = autism spectrum condition, TD = typically developing, VIQ = verbal IQ, PIQ = performance IQ, FSIQ = full-scale IQ, AQ = autism spectrum quotient.

Prior to participating in the study, all parents gave informed consent. The study was approved by the University Committee on Human Research Protection at East China Normal University (protocol code: HR025-2022).

Stimuli and apparatus

Most stimuli were validated to be CI-related or non-CI-related stimuli using the visual preference paradigm (Zhou et al., 2022), and the stimuli were also rated by 35 children with autism who did not participate in the current study. A final sample of 36 CI-related ($M = 0.76 \pm 0.07$) and 36 non-CI-related objects ($M = 0.25 \pm 0.07$) were chosen as the formal stimuli, and the preference scores between the two types of stimuli were significant ($t_{(35)} = 23.91$, $p < 0.001$). Both types of pictures have been documented in previous studies (DiCriscio et al., 2016; Sasson et al., 2008; Sasson & Touchstone, 2014; South et al., 2005; Unruh et al., 2016), including CI-related objects such as airplanes, cars, trains, clocks, and non-CI objects such as plants, clothes, and furniture. Both CI and non-CI distractors were set at 195 × 130 pixels in size. The target "a picture of the sun" was set as 130 × 130 pixels. The target was presented either on its own (ST condition) at 4.5° in the parafoveal location or 9° in the peripheral location on the right or left of the display, or it was presented with a distractor, which was positioned at the mirror opposite location to the target (NEAR and FAR conditions) or positioned at the foveal region (C condition).

The EyeLink Portable DUO (SR Research, Canada) with a 500 Hz sampling rate was adopted to collect eye-movement data. The display DELL screen was 15.6 inches with a refresh rate of 60 Hz and a 1920 × 1080 pixel resolution.

Procedures

Three-point calibration and validation procedures were performed before the experiment was initiated, and a one-point drift correction was performed before each trial of the experiment. An asterisk (*) was displayed for 800–1200 ms at the start of each trial across the four distractor conditions to ensure that participants had no expectations regarding the timing of the target/distractor appearances and to mitigate the potential impact of participant expectations on research results (Keehn, 2020). This was followed by: (1) a parafoveal or peripheral target (sun) presented in isolation for 2000 ms in the single target (ST) condition; (2) a distractor (CI or non-CI) presented foveally with the target presented at the parafoveal or peripheral location for 2000 ms in the central (C) distractor condition; (3) both the distractor and the target presented simultaneously at mirror symmetrical locations in the parafoveal (NEAR) or peripheral (FAR) fields. All trials ended with a 500 ms blank screen. See Figure 1 for an example of the trial sequence.

The experiment consisted of 96 formal trials, with 24 trials in each distractor condition. Both CI-related and non-CI-related distractors appeared in C, NEAR and FAR distractor conditions. All trials were pseudorandomly assigned across two blocks, and an ABBA order was implemented across participants. The instruction was: "Please look at the screen carefully, and when the 'sun' appears, look at it and ignore any irrelevant objects that might also be present on the screen". Before the formal eye-tracking trials, we created a PowerPoint presentation which included the instructions and pictures of the trial sequences. In the PowerPoint, there were 4–5 practice trials (distractor pictures were not related to the formal experiment images), and we asked participants to tell us what we were asking them to do, and to point to the relevant targets manually. Additionally, we included four practice trials before the formal set of 48 trials in each block. Each participant was asked to verbally describe what they were required to do in the study and the experimenter provided feedback to ensure comprehension of the task requirements.

Data analysis

Saccade latency (SL, the latency between target presentation and the first correct saccade initiation towards the target, ms), error rate (the proportion of the first saccades that were incorrectly directed towards the distractor), corrective rate (the proportion of first saccades towards the distractor that were followed by a second corrective saccade towards the target) and dwell time (the time spent looking at a specific Area-of-Interest, AOI, that was either CI-related AOI or non-CI-related AOI, ms) were analysed.

Eye-movement measures were analysed using the lmerTest package (version: 3.1-3) in R 4.3.0, employing either Linear Mixed Models (LMM) or Generalized Linear Mixed Models (GLMM), depending on whether the eye-movement measure was a continuous or a binary variable. In the analysis of SL, group (ASC, TD), distractor condition (ST, C, NEAR, FAR), and any interactions were

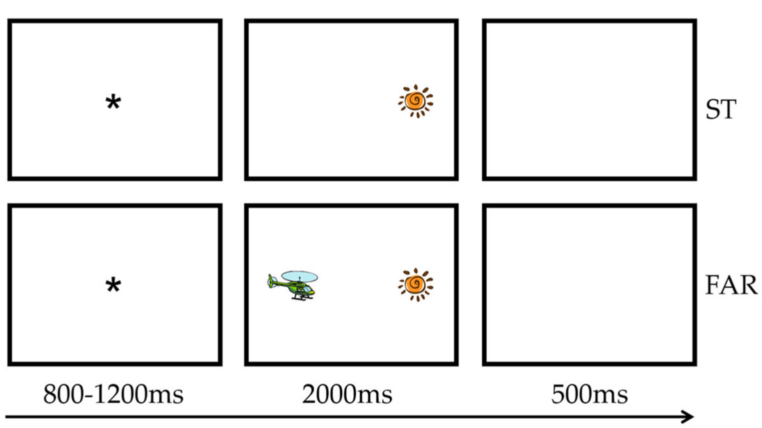

Figure 1. Example of experimental procedure. [To view this figure in color, please see the online version of this journal.]

Note: ST = single target, FAR = peripheral distractor. The airplane in the FAR condition is an example of a circumscribed interest related item, and the sun on the right is a lateral target.

considered to be fixed factors, and LMM were adopted to analyse SL as the first measure. We then added distractor type (CI, non-CI) into the LMM analysis to compare group (ASC, TD) differences under the three presentation conditions (C, NEAR, FAR) where a distractor was presented with the target (we did not include ST distractor condition in this session as only the target "sun" was present in this condition). For error rates and corrective rates (only mirror distractor conditions—NEAR and FAR—were analysed in these measures, as both the target and distractor were present simultaneously at the mirror side, making it challenging for participants to make a correct saccade. C and ST were not analysed in this session, as the target was present in the parafoveal/peripheral regions, and participants can easily make a correct saccade), GLMM were performed with group (ASC, TD), distractor condition (NEAR, FAR), distractor type (CI, non-CI), and any interactions were treated as fixed factors. Finally, we created the AOI (size: 220 × 160 pixels) for both CI and non-CI distractor regions so that we could compare participants' dwell time characteristics under distractor conditions (C, NEAR, FAR) also using LMM. Both participants and stimuli were treated as random factors in all LMM or GLMM analyses. Additionally, the BayesFactor package (version: 0.9.12-4.4) was employed to estimate the magnitude of both main and interaction effect models against the null model (including variations from both participants and stimuli), and in this analysis $BF_{10} > 1$ ($BF_{10} = \frac{p(data|H1)}{p(data|H0)}$) indicates that the alternative hypothesis has a greater influence than the null hypothesis (Wagenmakers et al., 2018).

Results

Saccade latency

A main effect of group ($b = 22.17$, $SE = 9.52$, $t = 2.33$, $p = 0.023$, $BF_{10} = 3.87$) indicated that children with autism showed increased SL (241 ± 5 ms) overall compared to TD children (232 ± 2 ms). The distractor condition effect ($F_{(3,\ 63.87)} = 301.68$, $p < 0.001$, $BF_{10} = 2.73e^{31}$) showed the expected fundamental remote distractor effect partly (RDE; Benson, 2008), whereby SL in distractor conditions (C, NEAR, and FAR) were significantly longer than in the non-distractor ST condition (161 ± 1 ms; $|t|s > 4.45$, $ps < 0.001$). Within those three distractor conditions, increased SL was shown for foveal distractor C condition (369 ± 5 ms) compared to both parafoveal NEAR (216 ± 3 ms; $b = 176.47$, $SE = 7.43$, $t = 23.74$, $p < 0.001$) and peripheral FAR distractor conditions (216 ± 3 ms; $b = 173.70$, $SE = 7.41$, $t = 23.44$, $p < 0.001$).

Table 2. Fixed effect estimates for saccade latency.

	b	*SE*	*t*	*p*
ASC vs. TD	22.17	9.52	2.33	0.023
C vs. FAR	173.70	7.41	23.44	< 0.001
C vs. NEAR	176.47	7.43	23.74	< 0.001
C vs.ST	227.23	11.08	20.51	< 0.001
FAR vs. NEAR	2.78	7.83	0.35	0.724
FAR vs. ST	53.53	11.36	4.71	< 0.001
NEAR vs. ST	50.75	11.38	4.46	< 0.001
C: ASC vs. TD	115.89	10.68	10.85	< 0.001
FAR: ASC vs. TD	−16.85	11.82	−1.43	0.844
NEAR: ASC vs. TD	−13.30	11.85	−1.12	0.951
ST: ASC vs. TD	2.93	9.98	0.29	1.000

Note: ASC = autism spectrum condition, TD = typically developing, C = central (foveal) distractor, FAR = peripheral distractor, NEAR = parafoveal distractor, ST = single target.

A significant interaction ($F_{(3,\ 3060.89)} = 105.80$, $p < 0.001$, $BF_{10} = 1.33e^{58}$) revealed that in the C condition (foveal distractor), children with ASC (441 ± 12 ms) showed prolonged SL compared to TD children (332 ± 5 ms; $b = 115.89$, $SE = 10.68$, $t = 10.85$, $p < 0.001$), but no group differences were observed for the other distractor conditions ($|t|s < 1.44$, $ps > 0.05$), and when stimulus type (CI, non-CI) was included as one of the fixed factors in the LMM, no effects related to stimulus type were found ($|t|s < 1.79$, $ps > 0.05$). See Table 2 for the detailed figures for the LMM results, and Figure 2 for SL across four distractor conditions.

Error rate

A significant main effect of group ($b = 0.69$, $SE = 0.18$, $z = 3.78$, $p < 0.001$, $BF_{10} = 21.13$) suggested that, overall, more saccade errors were made by children with autism (0.69 ± 0.01) than by TD children (0.55 ± 0.01). No other main effects or interactions were found to be significant ($|z|s < 1.79$, $ps > 0.05$).

Considering the high error rates across the two groups, it is possible that children were unable to follow the instructions and ended up looking at the target or distractors randomly. To eliminate this possibility, error rates were compared with the chance level (0.5), and significant differences from the chance level were found in ASC and TD groups respectively (ASC: $t = 13.68$, $p < 0.001$; TD: $t = 3.50$, $p < 0.001$). Furthermore, the significant distractor effect on SL also supports the view that both groups of children can follow the experimenter's instruction and endeavour to look at the targets.

Corrective saccade rate

A main effect of group ($b = 1.49$, $SE = 0.29$, $z = 5.07$, $p < 0.001$, $BF_{10} = 515.04$) showed that TD children made more corrective saccades (0.88 ± 0.01) than children with ASC

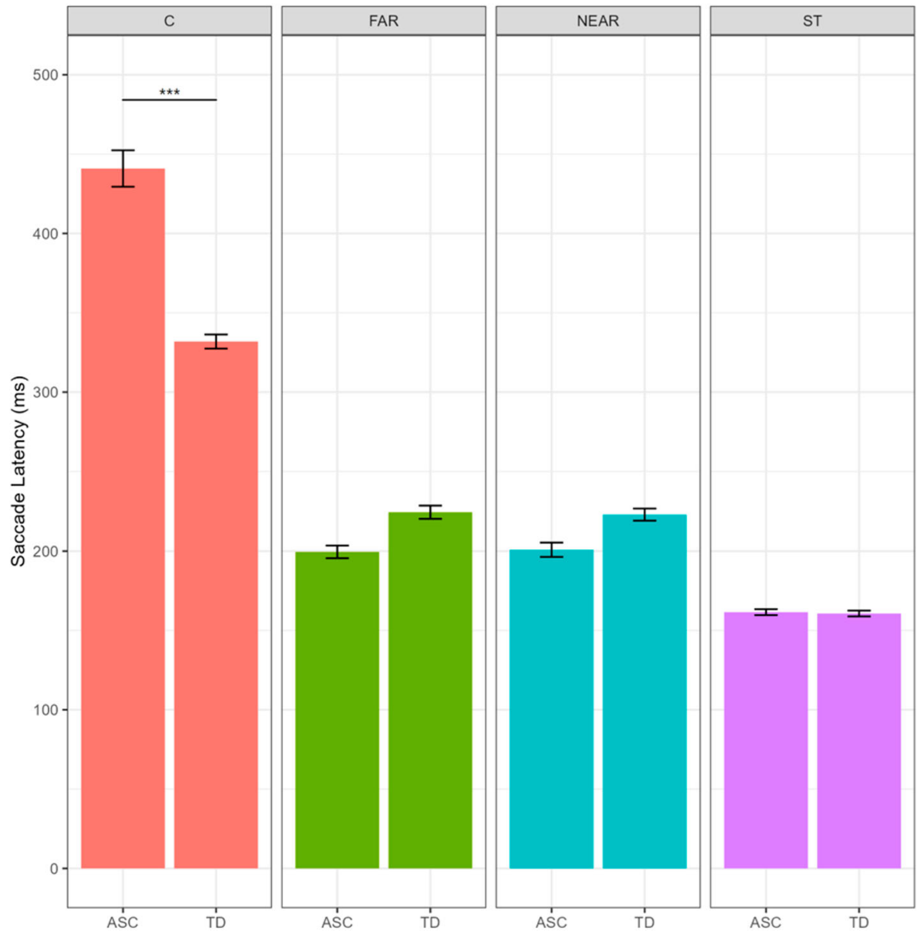

Figure 2. Group by distractor condition interaction results on saccade latency. [To view this figure in color, please see the online version of this journal.]

Note: ASC = autism spectrum condition, TD = typically developing, C = central (foveal) distractor, FAR = peripheral distractor, NEAR = parafoveal distractor, ST = single target.

(0.72 ± 0.02). No other main effects or interactions related to distractor types were found to be significant ($|z|$s < 1.96, *ps* > 0.05; or $BF_{10} < 1$). Importantly, in line with the error data, there was no evidence from this analysis to suggest that there was a difference in the corrective saccade rate for CI-related versus non-CI-related distractors between the groups.

Additionally, we also compared the corrective saccade rates with the chance level value (0.5), and ASC children's ($t = 13.43$, $p < 0.001$) and TD children's corrective performance ($t = 32.38$, $p < 0.001$) were significantly higher than the chance level, indicating that the second corrective saccades initiated towards the target were not initiated randomly.

Dwell time

Since it is well documented that individuals with ASC pay more attention to CI-related objects, and since we have found no evidence of this in the latency or error data in the current experiment, we conducted a further analysis of "dwell time" on the distractors to see if there was any evidence of increased voluntary processing of CI-related distractors in the ASC group when we calculated the total time spent looking at those distractors.

Dwell time (ms) is the time that eye-movement events (e.g. fixations, saccades, revisits) occur in a specific AOI region, and a higher dwell time could be associated with intrinsic preferences, motivation and voluntary attention (Mahanama et al., 2022). A significant main effect of group ($b = 508.63$, $SE = 54.41$, $t = 9.35$, $p < 0.001$, $BF_{10} = 1.76e^{10}$) suggested increased dwell time on distractor AOI regions in ASC children (855 ± 11 ms) compared to TD children (356 ± 7 ms). In addition, the significant main effect of distractor condition ($F_{(2,\ 65.87)} = 99.67$, $p < 0.001$, $BF_{10} = 6.61e^{14}$) showed that both groups of children dwelled more on foveal AOI distractors (797 ± 13 ms) relative to distractor AOI presented at NEAR (515 ± 12 ms; $b = 278.00$, $SE = 24.90$, $t = 11.17$, $p < 0.001$) and FAR locations (467 ± 12 ms; $b = 325.33$, $SE = 24.90$, $t = 13.07$, $p < 0.001$).

Table 3. Eye-movement measures across two distractor types in both groups (mean and SE).

		Saccade latency (ms)	Error rate (0–1)	Corrective rate (0–1)	Dwell time (ms)
ASC	CI	315 (11)	0.70 (0.02)	0.69 (0.02)	907 (16)
	non-CI	309 (10)	0.68 (0.02)	0.75 (0.02)	802 (15)
TD	CI	274 (4)	0.52 (0.02)	0.89 (0.02)	374 (10)
	non-CI	275 (4)	0.57 (0.02)	0.87 (0.02)	338 (9)

Note: ASC = autism spectrum condition, TD = typically developing, CI = circumscribed interests.

Additionally, an interaction between group and distractor type ($F_{(1,\ 4224.17)} = 14.89$, $p < 0.001$, $BF_{10} = 69.89$) showed an atypical visual preference for CI-related distractors (907 ± 16 ms) relative to non-CI distractors (802 ± 15 ms; $b = 103.50$, $SE = 22.80$, $t = 4.55$, $p < 0.001$) in the ASC group, and this difference was absent in the TD group (CI = 374 ± 10 ms, non-CI = 338 ± 9 ms; $|t| < 1.25$, $p > 0.05$). No other main effects or interactions were found to be significant ($Fs < 2.03$, $ps > 0.05$; or $BF_{10} < 1$). Described statistics for all of the above eye-movement measures in the current study are shown in Table 3.

Discussion

The aim of this study was to investigate the impact of CI-related objects on attentional orienting in individuals with and without autism, using eye-tracking technology by adopting a higher attentional level task, the remote distractor paradigm. This expectation was derived from the robust findings from visual preference studies which have reported that individuals with ASC pay more attention to CI-related objects (Sasson et al., 2008; Unruh et al., 2016; Valiyamattam et al., 2023). To achieve our aim, the current study employed the RDP with CI-related and non-CI-related distractors positioned at different locations in the visual field (including foveal, parafoveal, and peripheral regions). The task was to ignore the distractors and make a saccade (look) towards a laterally presented target (a sun). As expected, overall, weaker attentional control was observed in young children with ASC, and there was also some evidence of voluntary processing differences for CI-related distractors in that group.

In typical RDP experiments that employ simple geometric stimuli, foveal distractors produce the biggest RDE, and this effect decreases systematically as the distractor is positioned more peripherally (Walker et al., 1997). However, when distractors are more complex or larger in size, then it is not uncommon to observe similar effects for parafoveal and peripheral distractors (e.g. Zhang et al., 2021), and this is what we observed in the current study.

Moreover, a protracted endogenous disengagement from the foveal distractors was observed for children with autism in the central (foveal) distractor condition, providing further support for the attentional disengagement deficit hypothesis in ASC. It is known that disengagement deficits in ASC contribute to the emergence of the ASC phenotype (Keehn et al., 2013), and hence this was confirmed in the current study. The findings from the current study also align with prior findings of weak disengagements in toddlers with autism (Kleberg et al., 2017; Landry & Bryson, 2004; Zhou et al., 2022). For example, Zhang et al. (2020) adopted the same paradigm (RDP) to investigate attentional orienting using simple geometric figures as distractors and found a prolonged voluntary disengagement for the foveal distractor condition in children with ASC relative to neurotypical children.

However, what should be noted is that whether individuals with ASC experience difficulties in attentional disengagement is controversial, with conflicting findings reported in much of the previous research (Keehn, 2020). For example, Amestoy et al. (2021) conducted a two-year longitudinal study involving 82 children, adolescents, and adults with autism, finding preserved attentional disengagement from geometric figures in the gap-overlap paradigm compared to TD individuals. This intact disengagement was also found in other studies that used basic simple figures (e.g. Caldani et al., 2020; Crippa et al., 2013; Zalla et al., 2018), non-social figures (e.g. Wilson & Saldaña, 2019) and even social figures (Skripkauskaite et al., 2021).

We argue that these inconsistent findings, in relation to the findings in the current study, might result from methodological issues. One limitation of the traditional gap-overlap paradigm, which has been one of the most frequently used paradigms to investigate disengagement, concerns the overlap condition. In the overlap condition the centrally presented item is displayed for a duration of between 1000 and 3500 ms before the target appears, thus allowing both groups to pre-process the item prior to target appearance, and hence both groups could disengage swiftly and move the eyes to the target when it was displayed. This idea has been supported by a recent study (Zhou et al., 2022) who explored visual disengagement differences across toddlers with and without autism using the gap-overlap paradigm. The findings, similar to Amestoy et al. (2021), showed equivalent disengagement performance in both groups. However, when Zhou et al. (2022) modified the overlap task, by removing the opportunity to pre-process the foveal stimuli, disengagement differences were exhibited in young children with autism.

In the current study, no modulation effect by stimulus type was observed for saccade latency, and this finding is consistent with previous reports from both anti-saccade paradigms (DiCriscio et al., 2016) and traditional gap-overlap paradigms (Zhou et al., 2022). Both DiCriscio et al. (2016) and Zhou et al. (2022) have found that saccade latencies were comparative across CI-related and non-CI-related objects in both ASC and TD groups. These null effects for stimulus modulation on saccade latencies do not seem to fit with the expectation of increased disengagement for CI-related stimuli, given the consistent reports of a preference to "look at this type of stimulus for longer" in free viewing tasks. However, it might be that, unlike in passive viewing tasks (e.g. the preferential looking paradigm or visual research tasks), participants in the studies reported earlier, and here in the current study, were specifically instructed to disregard the (CI or non-CI) distractors and instead initiate a saccade to a lateral target location. Thus, the task demands in these types of studies differ from those studies where participants are able to freely look at CI-related or non-CI-related stimuli at their discretion. Under those conditions the preference for CI-related objects is clear in children with ASC. However, it is also clear from the findings of the current study and previous studies that have adopted orienting paradigms (RDP, the gap-overlap paradigm, and the anti-saccade paradigm) that stimulus type modulation can be overridden by the task demands. In these paradigms, the task can be successfully completed without the need to engage cognitive processing of complex visual stimuli like CI-related objects.

Analyses of error rates and corrective rates during orienting showed that both groups performed above the chance level. High error rates in both groups suggested the young children found it difficult to inhibit reflexive saccades towards the distractors. It has been documented that the inhibition system matures at 7–13 years old (Fukushima et al., 2000; Nicholls et al., 2019), and our 3–6 year-old participants were too young to control their top-down voluntary processing. High corrective rates, a second saccade initiated towards the target following a first saccade initiated towards the distractor, indicated that young participants could follow instructions and monitor their own incorrect eye movements to re-initiate saccades to the right position promptly, in both groups.

In the current study, children with autism showed poorer attentional control, with increased error rates, and decreased corrective rates on non-social distractors compared to TD counterparts. These findings align with previous evidence from anti-saccade (Amestoy et al., 2021; Luna et al., 2007) and go-no-go tasks (Uzefovsky et al., 2016), which suggests that individuals with autism are less able to inhibit involuntary orienting to distractors and promote a voluntary response to the targets. These challenges verify the fundamental attentional differences outlined in the executive dysfunctional theory (Hill, 2004) whereby response inhibition (the ability to resist impulsive actions) is divergent in children with autism. Moreover, these inhibitory failures to suppress reflexive saccades are reflected in cerebellar circuit alternations in ASC (Mosconi et al., 2013).

Additionally, some evidence of a modulation effect on distractors was found on dwell time in children with autism. An atypical preference for CI-related objects over non-CI objects was observed for participants with ASC. This result fits with findings from free viewing tasks which report prolonged looking time on CI-related items (Sasson & Touchstone, 2014; Unruh et al., 2016). In the current study, the dwell differences on CI-related objects indirectly confirmed the validity of the research materials. Moreover, unlike in prior free-viewing studies (e.g. Sasson et al., 2008), the children in the current study were instructed to ignore the distractors and yet still there was evidence in the dwell time measure of more attention allocated to the CI-related distractors in young children with autism. The processing bias for CI-related stimuli that has been shown in previous passive-looking paradigms (Unruh et al., 2016) is not supported in the traditional RDP measures of latency and errors, but the bias has received support from the dwell time measure in the current study. We suggest that the dwell time measure, which is similar to "total looking time" reflects more voluntary attentional orienting, and it is more likely that attentional differences will be observed for CI-related objects in the voluntary attentional domain.

Some limitations in the current study should be considered and further examined in future studies. Firstly, we did not investigate gender differences, and some recent studies have suggested there may be gender differences in the types of objects that result in circumscribed interest for individuals with autism (Harrop et al., 2018). This is an area worthy of future investigation. Secondly, paradigms that permit enhanced engagement with CI-related objects might be better suited to investigate visual disengagement differences in individuals with autism, rather than paradigms where it is not necessary to process CI-related objects in order to complete the task at hand.

Conclusion

The current study explored the influence of CI-related and non-CI-related distractors on visual orienting in young children with and without ASC. The findings provide support for basic attentional orienting differences in young children with ASC, and some evidence for the expected bias for CI-related stimuli in ASC. However, the findings also raise the question as to whether paradigms that were set up to investigate basic attentional or oculomotor control are suitable to detect attentional processing differences for complex visual stimuli. We suggest that in such paradigms (e.g. the RDP, the gap-overlap paradigm, the anti-saccade paradigm), basic task demands might actually mask any stimulus preference biases, as in those paradigms such stimuli do not have to be fully processed in the first place in order to complete the task. Hence our findings and our interpretation of these findings offer a solution to a puzzle, namely, why attentional disengagement in individuals with ASC is often reported to be the same for CI-related and non-CI objects when traditional eye-movement paradigms are adopted to investigate the effects of high-level complex visual stimuli. This leads us to conclude that future studies that aim to investigate attentional orienting for CI-related stimuli in individuals with ASC might be best suited to adopt paradigms where the task demands do not mask such biases.

Acknowledgements

We are grateful to all young participants and their parents in this study. We wish to thank all participating kindergartens and the Yitong Autism Research and Service Centre in Tianjin (special thanks are given to Shiju Bi, Yuanping Zhang and Jiayi Zhao). We also acknowledge the support for this work given by Lichao Kang, Ioana Andrada Mihalache, and Xiaoyuan Yuan. Finally, our special thanks are given to Qiang Huang and Yanjie Chu, who provided much support and assistance in this research.

Data availability

Data can be found on the OSF at the following link: https://osf.io/s9y3f.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the 2022 Education Research Project of Shanghai Philosophy and Social Science Planning (A2022009).

Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the University Committee on Human Research Protection, East China Normal University (protocol code: HR025-2022).

References

Ambarchi, Z., Boulton, K. A., Thapa, R., Thomas, E. E., DeMayo, M. M., Sasson, N. J., Hickie, I. B., & Guastella, A. J. (2023). Evidence of a reduced role for circumscribed interests in the social attention patterns of children with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *53*(10), 3999–4011. https://doi.org/10.1007/s10803-022-05638-4

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Ames, C., & Fletcher-Watson, S. (2010). A review of methods in the study of attention in autism. *Developmental Review*, *30*(1), 52–73. https://doi.org/10.1016/j.dr.2009.12.003

Amestoy, A., Guillaud, E., Bucchioni, G., Zalla, T., Umbricht, D., Chatham, C., Murtagh, L., Houenou, J., Delorme, R., Moal, M. L.-L., Leboyer, M., Bouvard, M., & Cazalets, J.-R. (2021). Visual attention and inhibitory control in children, teenagers and adults with autism without intellectual disability: Results of oculomotor tasks from a 2-year longitudinal follow-up study (InFoR). *Molecular Autism*, *12*(1), 71. https://doi.org/10.1186/s13229-021-00474-2

Auyeung, B., Baron-Cohen, S., Wheelwright, S., & Allison, C. (2008). The Autism Spectrum Quotient: Children's version (AQ-child). *Journal of Autism and Developmental Disorders*, *38*(7), 1230–1240. https://doi.org/10.1007/s10803-007-0504-z

Benson, V. (2008). The influence of complex distractors in the remote distractor paradigm. *Journal of Eye Movement Research*, *2*(3), 1–15. https://doi.org/10.16910/jemr.2.3.2

Caldani, S., Steg, S., Lefebvre, A., Atzori, P., Peyre, H., Delorme, R., & Bucci, M. P. (2020). Oculomotor behavior in children with autism spectrum disorders. *Autism*, *24*(3), 670–679. https://doi.org/10.1177/1362361319882861

Crippa, A., Forti, S., Perego, P., & Molteni, M. (2013). Eye-hand coordination in children with high functioning autism and Asperger's disorder using a gap-overlap paradigm. *Journal of Autism and Developmental Disorders*, *43*(4), 841–850. https://doi.org/10.1007/s10803-012-1623-8

DiCriscio, A. S., Miller, S. J., Hanna, E. K., Kovac, M., Turner-Brown, L., Sasson, N. J., Sapyta, J., Troiani, V., & Dichter, G. S. (2016). Brief report: Cognitive control of social and nonsocial visual attention in autism. *Journal of Autism and Developmental Disorders*, *46*(8), 2797–2805. https://doi.org/10.1007/s10803-016-2804-7

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fukushima, J., Hatta, T., & Fukushima, K. (2000). Development of voluntary control of saccadic eye movements: I. Age-related changes in normal children. *Brain and Development*, *22*(3), 173–180. https://doi.org/10.1016/S0387-7604(00)00101-7

Harrop, C., Amsbary, J., Towner-Wright, S., Reichow, B., & Boyd, B. A. (2019). That's what I like: The use of circumscribed interests within interventions for individuals with autism spectrum disorder. A systematic review. *Research in Autism Spectrum Disorders*, *57*, 63–86. https://doi.org/10.1016/j.rasd.2018.09.008

Harrop, C., Jones, D., Zheng, S., Nowell, S., Boyd, B. A., & Sasson, N. (2018). Circumscribed interests and attention in autism:

The role of biological sex. *Journal of Autism and Developmental Disorders*, *48*(10), 3449–3459. https://doi.org/10.1007/s10803-018-3612-z
Hill, E. L. (2004). Executive dysfunction in autism. *Trends in Cognitive Sciences*, *8*(1), 26–32. https://doi.org/10.1016/j.tics.2003.11.003
Keehn, B. (2020). Attentional disengagement. In F. Volkmar (Ed.), *Encyclopedia of autism spectrum disorders*. Springer. https://doi.org/10.1007/978-1-4614-6435-8_102441-1
Keehn, B., Müller, R.-A., & Townsend, J. (2013). Atypical attentional networks and the emergence of autism. *Neuroscience and Biobehavioral Reviews*, *37*(2), 164–183. https://doi.org/10.1016/j.neubiorev.2012.11.014
Kleberg, J. L., Thorup, E., & Falck-Ytter, T. (2017). Reduced visual disengagement but intact phasic alerting in young children with autism. *Autism Research*, *10*(3), 539–545. https://doi.org/10.1002/aur.1675
Kohls, G., Antezana, L., Mosner, M. G., Schultz, R. T., & Yerys, B. E. (2018). Altered reward system reactivity for personalized circumscribed interests in autism. *Molecular Autism*, *9*(1), 9. https://doi.org/10.1186/s13229-018-0195-7
Landry, R., & Bryson, S. E. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry*, *45*(6), 1115–1122. https://doi.org/10.1111/j.1469-7610.2004.00304.x
Lockwood Estrin, G., Mason, L., Arora, R., Bhavnani, S., Dasgupta, J., Gulati, S., Gliga, T., & Johnson, M. H. (2024). Attention control in autism: Eye-tracking findings from pre-school children in a low- and middle-income country setting. *Autism*, *28*(1), 43–57. https://doi.org/10.1177/13623613221149541
Luna, B., Doll, S. K., Hegedus, S. J., Minshew, N. J., & Sweeney, J. A. (2007). Maturation of executive function in autism. *Biological Psychiatry*, *61*(4), 474–481. https://doi.org/10.1016/j.biopsych.2006.02.030
Mahanama, B., Jayawardana, Y., Rengarajan, S., Jayawardena, G., Chukoskie, L., Snider, J., & Jayarathna, S. (2022). Eye movement and pupil measures: A review. *Frontiers in Computer Science*, *3*. https://www.frontiersin.org/articles/10.3389fcomp.2021.733531
Mo, S., Liang, L., Bardikoff, N., & Sabbagh, M. A. (2019). Shifting visual attention to social and non-social stimuli in Autism Spectrum Disorders. *Research in Autism Spectrum Disorders*, *65*, 56–64. https://doi.org/10.1016/j.rasd.2019.05.006
Mosconi, M. W., Luna, B., Kay-Stacey, M., Nowinski, C. V., Rubin, L. H., Scudder, C., Minshew, N., & Sweeney, J. A. (2013). Saccade adaptation abnormalities implicate dysfunction of cerebellar-dependent learning mechanisms in Autism Spectrum Disorders (ASD). *PLoS One*, *8*(5), e63709. https://doi.org/10.1371/journal.pone.0063709
Nicholls, V. I., Jean-Charles, G., Lao, J., De Lissa, P., Caldara, R., & Miellet, S. (2019). Developing attentional control in naturalistic dynamic road crossing situations. *Scientific Reports*, *9*(1), 4176. https://doi.org/10.1038/s41598-019-39737-7
Sasson, N. J., Dichter, G. S., & Bodfish, J. W. (2012). Affective responses by adults with autism are reduced to social images but elevated to images related to circumscribed interests. *PLoS One*, *7*(8), e42457. https://doi.org/10.1371/journal.pone.0042457
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
Skripkauskaite, S., Slade, L., & Mayer, J. (2021). Attentional shifting differences in autism: Domain general, domain specific or both? *Autism*, *25*(6), 1721–1733. https://doi.org/10.1177/13623613211001619
South, M., Ozonoff, S., & McMahon, W. M. (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/s10803-004-1992-8
Unruh, K. E., Sasson, N. J., Shafer, R. L., Whitten, A., Miller, S. J., Turner-Brown, L., & Bodfish, J. W. (2016). Social orienting and attention is influenced by the presence of competing nonsocial information in adolescents with autism. *Frontiers in Neuroscience*, *10*, 586. https://doi.org/10.3389/fnins.2016.00586
Uzefovsky, F., Allison, C., Smith, P., & Baron-Cohen, S. (2016). Brief report: The go/no-go task online: Inhibitory control deficits in autism in a large sample. *Journal of Autism and Developmental Disorders*, *46*(8), 2774–2779. https://doi.org/10.1007/s10803-016-2788-3
Valiyamattam, G. J., Katti, H., Chaganti, V. K., O'Haire, M. E., & Sachdeva, V. (2023). Circumscribed interests in autism: Can animals potentially re-engage social attention? *Research in Developmental Disabilities*, *137*, 104486. https://doi.org/10.1016/j.ridd.2023.104486
Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E.-J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., … Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, *25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7
Walker, R., Deubel, H., Schneider, W. X., & Findlay, J. M. (1997). Effect of remote distractors on saccade programming: Evidence for an extended fixation zone. *Journal of Neurophysiology*, *78*(2), 1108–1119. https://doi.org/10.1152/jn.1997.78.2.1108
Wang, Q., Lu, L., Zhang, Q., Fang, F., Zou, X., & Yi, L. (2018). Eye avoidance in young children with autism spectrum disorder is modulated by emotional facial expressions. *Journal of Abnormal Psychology*, *127*(7), 722–732. https://doi.org/10.1037/abn0000372
Wechsler, D. (2014). *Wechsler preschool and primary scale of intelligence—fourth CN edition (WPPSI-IV CN)*. King-May Pyschological Assessment Technology and Development LTD.
Wilson, C. E., & Saldaña, D. (2019). No evidence of atypical attentional disengagement in autism: A study across the spectrum. *Autism*, *23*(3), 677–688. https://doi.org/10.1177/1362361318768025
Yerys, B. E. (2015). Chapter three—An update on the neurobiology of repetitive behaviors in autism. In R. M. Hodapp & D. J. Fidler (Eds.), *International review of research in developmental disabilities* (Vol. 49, pp. 91–150). Academic Press. https://doi.org/10.1016/bs.irrdd.2015.06.006
Zalla, T., Seassau, M., Cazalis, F., Gras, D., & Leboyer, M. (2018). Saccadic eye movements in adults with high-functioning

autism spectrum disorder. *Autism*, *22*(2), 195–204. https://doi.org/10.1177/1362361316667057

Zhang, L., Yan, G., & Benson, V. (2021). The influence of emotional face distractors on attentional orienting in Chinese children with autism spectrum disorder. *PLoS One*, *16*(5), e0250998. https://doi.org/10.1371/journal.pone.0250998

Zhang, L., Yan, G., Zhou, L., Lan, Z., & Benson, V. (2020). The influence of irrelevant visual distractors on eye movement control in Chinese children with autism spectrum disorder: Evidence from the remote distractor paradigm. *Journal of Autism and Developmental Disorders*, *50*(2), 500–512. https://doi.org/10.1007/s10803-019-04271-y

Zhou, L., Zhang, L., Xu, Y., Yang, F., & Benson, V. (2022). Attentional engagement and disengagement differences for circumscribed interest objects in young Chinese children with autism. *Brain Sciences*, *12*(11), 1461. https://doi.org/10.3390/brainsci12111461