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Attentional disengagement differences in young children with autism: A comparative eye-movement study using static and dynamic stimuli

Li Zhou [a,b,c], Valerie Benson [d,*]

[a] School of Educational Sciences, Xinjiang Normal University, Urumqi, China
[b] Xinjiang Higher Education Development Research Centre, Urumqi, China
[c] Faculty of Education, East China Normal University, Shanghai, China
[d] School of Psychology and Humanities, University of Central Lancashire, Preston, UK

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ABSTRACT

Weak attentional disengagement represents a crucial concern in children with Autism Spectrum Condition (ASC). Failure to disengage from attended stimuli has obvious consequences for the development of everyday communication skills, and in the real world, stimuli are often dynamic as well as static. In this study, we recorded eye movements and investigated attentional disengagement in young Chinese children with and without ASC for static and dynamic stimuli. Our approach employed the gap-overlap paradigm (GOP) with stimuli consisting of static (Experiment 1: 44 ASC, 47 typically developing (TD)) or dynamic (Experiment 2: 26 ASC, 26 TD) geometric figures. Basic oculomotor function was intact in both groups. No significant group differences were observed for reflexive saccades and attentional orienting between ASC and TD children using the classic GOP. However, young children with ASC consistently exhibited prolonged voluntary disengagement (longer saccade latencies) in a modified-overlap task across both stimulus types. Furthermore, ASC children demonstrated more delayed disengagement when presented with dynamic foveal stimuli consisting of repetitive motion compared to random motion, and this effect was absent in TD children. These findings reflect how attentional biases to both static and repetitive dynamic stimuli impact upon visual disengagement, and hence have the potential to influence future development of social cognition in individuals with ASC.

1. Introduction

Autism Spectrum Condition (ASC) is characterized as a neurodevelopmental disorder marked by deficits in social communication and interaction, alongside restricted interests and repetitive behaviours (American Psychiatric Association, 2013). Beyond these cardinal symptoms, a wealth of research has highlighted the presence of atypical visual disengagement in individuals with ASC (Keehn et al., 2021; Kleberg et al., 2017; Sabatos-DeVito et al., 2016), which may serve as an early marker for high-risk ASC infants at just 12 months of age (Bryson et al., 2018; Zwaigenbaum et al., 2005). Moreover, attentional disengagement challenges reverberate throughout the developmental trajectory in ASC, spanning from early childhood to adulthood (Sacrey et al., 2014). This intricate dysfunction intertwines with an array of developmental hurdles in ASC, particularly among autistic children in the areas of joint

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[*] Correspondence to: School of Psychology and Humanities, University of Central Lancashire, Preston PR1 2HE, UK.
E-mail address: vbenson3@uclan.ac.uk (V. Benson).

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attention (Muratori et al., 2019), emotional regulation (Bryson et al., 2018), auditory word recognition (Venker, 2017), and deficits in other aspects of social cognition (Elison et al., 2013; McLaughlin et al., 2021; Sabatos-DeVito et al., 2016).

Minimal research has provided evidence of disengagement characteristics across ASC and typically developing (TD) children for both static and dynamic stimuli. In one study, Sabatos-DeVito and colleagues (2016) examined attentional disengagement across three foveal stimulus types (visual-static, visual-dynamic, visual-dynamic and auditory) in children with ASC and other developmental disorders, as well as TD children. They found similar disengagement behaviours (saccade accuracies and saccade latency, SL) across ASC children and the other participant groups in the visual domain, but weaker disengagement was observed in ASC for multimodal compared to unimodal stimuli. In another study, Wilson and Saldaña (2019) manipulated the motion and contrast of peripheral targets (still versus moving) during visual disengagement, and found that disengagement performance was comparable across ASC and TD children. These studies suggested that ASC children have intact visual disengagement abilities in line with control counterparts when processing both static and dynamic visual properties, but this view has not been consistently supported.

Considering the profile for static stimuli, in line with the above two studies, most studies report intact visual disengagement in children with ASC, including those with high-functioning and mixed abilities. For example, early research (van der Geest et al., 2001), employing static geometric figures, indicated that children with ASC can achieve disengagement proficiency similar to TD peers, as demonstrated by comparable SL. Additional eye-tracking studies further supported this unimpaired attentional disengagement in ASC for various static stimuli, such as basic shapes (e.g., squares, circles), animals, fruits, houses and faces (Amestoy et al., 2021; Caldani et al., 2020; J. Fischer et al., 2014, 2016; Skripkauskaite et al., 2021; Zalla et al., 2018). Yet, recent research by Zhou et al. (2022) found disrupted visual disengagement in ASC relative to TD children for static non-social stimuli (e.g. plants and vehicles). The discrepancy with prior findings may partly arise from limitations in the traditional gap-overlap paradigm (GOP), particularly its most commonly used task, the classic-overlap (CO) task, which is designed to assess attentional disengagement. However, by design, the CO task presents the disengaging (foveal) stimulus before the target, which allows for the pre-processing of the stimulus prior to target onset. This pre-processing would facilitate rapid attentional shifts to the target upon its appearance, potentially masking underlying attentional disengagement problems in children with ASC in the presence of two competing stimuli. This might explain why many previous GOP studies failed to detect group differences. Indeed, Zhou et al. (2022) argued that the traditional GOP may lack the sensitivity needed to reveal such potential attentional disengagement differences.

To address this limitation, Zhou et al. (2022) initially employed a modified-overlap (MO) task that presented foveal stimuli and lateral targets simultaneously. This modification removed the availability of exogenous cues in the presence of the central stimuli. This methodological innovation supported the enhanced sensitivity of the MO task (in Zhou et al.'s Experiment 3) compared to the traditional GOP sub-tasks (in Zhou et al.'s Experiment 2) and revealed visual disengagement differences at the group level. However, Zhou et al. (2022) employed very complex static stimuli which could have produced effects that were unrelated to basic attentional processes. To delineate the influence of potential confounding factors from stimulus complexity, a foundation experiment employing simple static figures becomes imperative. Hence, our first objective in the current study is to investigate basic attentional disengagement in ASC for both the classic GOP (including CO, baseline (BA) and gap (GAP) sub-tasks) and the modified-overlap task employing simple static geometric figures as stimuli in Experiment 1.

Considering the influence of dynamic stimuli, only a small number of studies have employed this type of stimulus in young children with ASC. For example, Landry and Bryson (2004) highlighted the challenges faced by young ASC children in disengaging attention from dynamic geometric figures, as evidenced by notable slower SL and increased failure-disengagement trials compared to TD counterparts. Additionally, Bryson et al. (2018) expanded the scope to high-risk infants subsequently diagnosed with ASC, revealing similar visual disengagement challenges in response to dynamic simple figures in ASC, as opposed to TD infants. It is worth noting that some of the previous studies may have adopted dynamic stimuli related to repetitive (REP) motion patterns, and this type of motion has been shown to hold fascination in individuals with ASC (American Psychiatric Association, 2013). REP movements are believed to serve as an intrinsic protecting mechanism (Turner, 1999), offering a sense of security and relief from any internal stress evoked by unpredictable surroundings (or movements). In addition, such a REP profile may trigger heightened activity in the brain's reward circuits (Dichter & Adolphs, 2012). This inclination toward visual REP is evident in daily-life behaviours in ASC. For example, studies have shown greater fixation on rotating fan blades or spinning car wheels in young individuals with ASC (Mooney et al., 2006; Pierce et al., 2011). Recent evidence based on the visual-preference paradigm has also indicated an atypical bias towards REP movements over random (RAN) movements in young children with ASC, as reported by Li et al. (2021) and Wang et al. (2018). In this context, it seems plausible to suggest that children with ASC might encounter challenges in disengaging from such dynamic stimuli, and these challenges would be expected to be absent in TD children. However, it is important to underscore that the evidence provided above for visual-preference studies, while insightful, cannot definitively establish the intricacies of attentional disengagement. As such, the central goal of Experiment 2 aimed to investigate attentional disengagement specifically in the realm of dynamic stimuli (including REP and RAN motion types), employing geometric figures analogous to those utilized in Experiment 1.

Additionally, and in light of mixed reports of basic oculomotor function in ASC (e.g., Avni et al., 2021; Caldani et al., 2020), we aim to analyse basic eye-movement measures to assess fundamental oculomotor function in our participants. This is important and allows us to clarify whether any observed differences in our different conditions in Experiment 1 result from genuine attention processing differences between ASC and TD children, and not from differences in basic eye-movement abilities. This analysis included basic eye-movement measures for different target eccentricities, and this in turn also allowed us to explore attentional disengagement across different eccentricities.

Our hypothesis for the main aims of our study was that we expected to observe weak attentional disengagement abilities in young children with ASC across both static and dynamic stimulus types. Specifically, we predicted slower SL, increased costs to disengage from the foveal focus and/or more failures to disengage completely from the central stimuli in the ASC group. This hypothesis is grounded in the assumption that both ASC and TD groups exhibit equivalent oculomotor control. Additionally, we predicted in Experiment 2, if it is the case that ASC children are more challenged to disengage from dynamic stimuli with a repeated motion compared to dynamic stimuli with a random motion pattern, then we would predict a modulation effect of the two different motion types. Specifically, we predicted prolonged attentional disengagement from REP motion over RAN motion exclusively for the ASC group.

2. Experiment 1

2.1. Methods

2.1.1. Participants

A power analysis using G*Power 3.1.9.7 (Faul et al., 2007) ensured the adequacy of the sample size. Parameters were set to 0.95 power (1-β), $\alpha = 0.05$, a medium effect size ($f = 0.25$; Cohen, 1988), $\varepsilon = 1$ for the default nonsphericity correction, and an assumed correlation of 0.5 among repeated measures (reflecting expected correlations between tasks and eccentricities), consistent with methodologies in published studies (Wang et al., 2021; Zhou et al., 2024). Specifically, this analysis indicated that a repeated-measures ANOVA (RM-ANOVA), with group (ASC, TD) as the between-subjects factor and both task (MO, CO, BA, GAP) and eccentricity (4°, 8°) as within-subjects factors, required a minimum of 24 participants (12 per group) to detect the interaction effect.

A total of 91 young participants were recruited in Experiment 1. Among them, 44 ASC young children ($M_{\text{age}} = 70.88$ months) were recruited from an Autism Research Service Centre in Tianjin. The diagnosis of autism for young ASC children was officially confirmed by at least one experienced clinician in licensed hospitals, taking into account the diagnostic criteria outlined in DSM-5 (American Psychiatric Association, 2013). Additionally, 47 TD children ($M_{\text{age}} = 67.71$ months) were recruited from three different kindergartens in Tianjin and Jiaozuo. The absence of any history of brain damage and/or neurodevelopmental deficits was confirmed by the parents of the TD children.

The participant matching process was conducted as follows: First, we collected relevant data (e.g., age, gender) for children with ASC. Obtaining such data can be challenging, as these children may have difficulty understanding and cooperating with the requirements of intelligence tests (e.g., Wechsler Preschool and Primary Scale of Intelligence). Once the ASC participants' data were obtained, we recruited TD children from local kindergartens who matched the ASC children in age and gender. Subsequently, we administered the same intelligence tests to the TD children to ensure their IQ scores (verbal, performance, and full-scale) were comparable to those of the ASC group. The assessment of participants' IQ was conducted using the Chinese version of either the Wechsler Preschool and Primary Scale of Intelligence (Wechsler, 2014) or the Wechsler Intelligence Scale for Children (Wechsler, 2008). This careful matching was implemented to ensure that any observed differences in eye-tracking data were not confounded by differences in participant characteristics, thereby avoiding potential confounding variables. See Table 1 for participant characteristics.

The Chinese version of the Autism Spectrum Quotient: Children's version (AQ; Auyeung et al., 2008) was employed as a validation tool, and the scores of diagnosed ASC children were significantly higher than those of their control peers ($t_{(89)} = 8.76, p < 0.001$). Prior to the commencement of the experiment, informed consent was obtained from the parents of all young ASC and TD participants. Furthermore, the University Committee on Human Research Protection at East China Normal University granted ethical approval to the current study (protocol code: HR025–2022).

2.1.2. Stimulus and Apparatus

Stimuli were generated using Adobe Photoshop, with screen dimensions of 1920 × 1080 pixels, and stimuli were set on a black

Table 1
Demographic data (mean and SD) of ASC and TD groups in Experiment 1 and Experiment 2.

Experiment 1	ASC	TD	χ^2/t
n	44	47	N/A
Male/Female	37/7	38/9	0.17
Age (months)Range	70.88 (12.86)39.66 −95.43	67.71 (8.76)42.73 −82.16	1.38
VIQRange	104.43 (17.22)79 −146	103.38 (9.93)83 −129	0.36
PIQRange	111.21 (15.99)80 −145	108.60 (10.21)89 −135	0.93
FSIQRange	106.73 (14.71)80 −139	107.36 (8.58)83 −125	−0.25
AQRange	76.41 (13.02)46 −107	53.81 (11.59)35 −86	8.76***
Experiment 2	ASC	TD	χ^2/t
n	26	26	N/A
Male/Female	22/4	19/7	1.04
Age (months)Range	68.07 (12.60)40.33 −89.90	72.20 (6.20)56.06 −81.93	-1.50
VIQRange	105.00 (12.56)79 −132	101.27 (11.36)85 −123	1.12
PIQRange	112.54 (14.67)80 −145	106.62 (10.54)91 −121	1.67
FSIQRange	109.39 (11.86)80 −130	104.12 (11.46)87 −131	1.63
AQRange	74.39 (12.08)47 −94	56.15 (9.72)37 −72	6.00***

Note. ASC = autism spectrum condition; TD = typically developing; VIQ = verbal IQ; PIQ = performance IQ; FSIQ = full-scale IQ; AQ = autistic quotient.
*** $p < 0.001$.

background. The fixation point consisted of a yellow cross (approximately 0.5° × 0.5° in size), with a small red dot located at the centre. Both the foveal stimulus (yellow circle) and target (yellow square) were the same size as the fixation point. The choice of employing simple shapes as central and target stimuli was primarily based on their low visual complexity and familiarity with young children. The target square appeared randomly on either the right or left side, positioned at an eccentricity of 4° (parafoveal regions) or 8° (peripheral regions) from the centre.

The participant's right eye was tracked using the EyeLink Portable DUO eye-tracker (SR Research, Canada) at a sampling rate of 500 Hz. All stimuli were displayed on a 15.6-inch DELL monitor with a refresh rate of 60 Hz, placed at 52 cm from the participant's eyes. A chinrest was employed to ensure head stability during the experiment.

2.1.3. *Procedure*

A three-point calibration and validation were initially performed, followed by a drift calibration before each trial. Subsequently, participants completed four tasks (MO, CO, BA, and GAP) in a pseudorandom order. Each trial began with a central fixation for 500–800 ms. In the MO condition, the foveal stimuli (circle) and the parafoveal/peripheral target (square) overlapped for 1500 ms. In the CO condition, the foveal circle was presented in isolation for 800–1200 ms, followed by an overlap with the lateral target for 1500 ms. In the BA condition, the foveal stimuli disappeared simultaneously with the appearance of the target, using the same timing setup. In the GAP condition, a temporary gap of 200–250 ms was introduced between the display of the foveal stimuli (800–1200 ms) and the target square (1500 ms). All targets appeared randomly on the left or right side, at two different eccentricities (4°, 8°). Fig. 1 shows an example of a trial sequence in Experiment 1.

The experiment comprised a total of 80 formal trials, with 20 trials allocated to each of the four tasks (MO, CO, BA, and GAP). These trials were organized into two blocks of 40 trials each (10 trials per task condition). Within each block, trials were presented in a pseudorandom order (e.g., MO, GAP, CO, GAP, BA, etc.), preventing participants from predicting the upcoming tasks. Furthermore, to ensure variability, no single task was presented on more than three consecutive trials. Across all participants, an ABBA order was followed between the two blocks. Children were instructed to fixate on the foveal stimuli and then look at the lateral square when it appeared. Children's understanding of the tasks was checked individually prior to testing by showing each child an example PowerPoint slide and asking them to tell the experimenter in words what they were being asked to do in the study.

2.2. *Statistical methods and results*

The eye movement data was exported using the DataViewer 4.2 software (SR Research Ltd). During the data analysis phase, we examined participants' oculomotor function first, followed by the analysis of attentional disengagement. In the analyses of oculomotor function our primary focus was on the basic eye-movement characteristics of both ASC and TD children. Given the multiple eye-tracking measures examined, we implemented stringent statistical controls to mitigate the risk of Type I errors. Specifically, we adopted a conservative alpha level of < 0.01 for most tests, and in some instances, a threshold of < 0.001. Furthermore, we applied the Holm-Bonferroni post-hoc test where appropriate to control the family-wise error rate. The same statistical approach was employed for Experiment 2.

2.2.1. *Basic oculomotor function analysis and results*

Express saccade rate (SL within 80–120 ms), anticipatory saccade rate (SL less than 80 ms), gain (the ratio of the saccade amplitude over the target eccentricities), and the main sequence effect (the linear relationships between saccade amplitude and saccade duration or saccade peak velocity, were used to assess eye-movement function; Bahill et al., 1975). The gain was analysed using linear

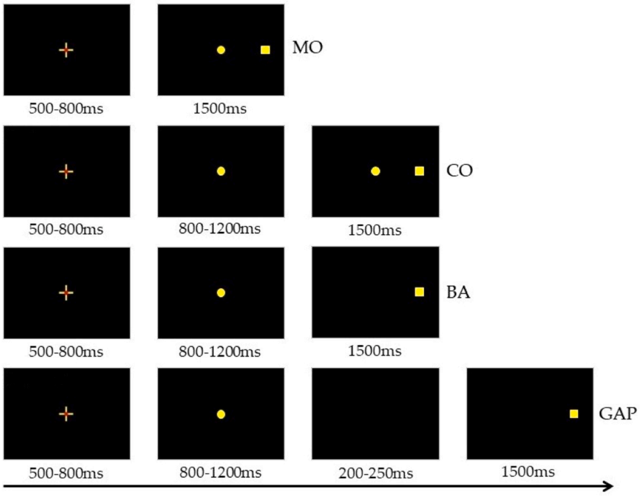


Fig. 1. Experimental Procedure in Experiment 1. Note. MO = modified-overlap; CO = classic-overlap; BA = baseline.

mixed-effects models (LMM) with the lme4 package (Bates et al., 2015) and bruceR package (Bao, 2022) in R 4.3.0 (R Core Team, 2023), while the express saccade rate and anticipatory saccade rate were analysed using RM-ANOVA, due to limited data points (The two groups of participants had few express and anticipatory saccades). In all analyses, group was treated as the between-subject factor, and both task and eccentricity were considered as within-subject factors. For the main sequence analysis, following the published study (Zhang et al., 2020), we employed LMM with group and participants' saccade amplitude as fixed factors, and saccade duration or saccade peak velocity as dependent variables. Additionally, both participants and stimuli were treated as random factors in the LMM analysis.

Express Saccade Rate. As expected, among the express saccade trials, the GAP task accounted for 71.43 % of express saccades, followed by the CO task (18.63 %), BA task (6.21 %) and MO task (3.73 %). Therefore, a significant main effect of task was observed ($F_{(3,\ 261)} = 24.81$, $p < 0.001$), revealing that young children exhibited a higher frequency of express saccades in the GAP condition (3.36 % ± 0.45 %), compared to the BA (0.40 % ± 0.18 %), CO (0.65 % ± 0.17 %), and MO (0.38 % ± 0.18 %) conditions. No other marked main effects or interactions relative to group were found. The GAP task produces more express saccades, because the temporary gap suppresses activation of fixation cells in the rostral superior colliculus which enables the generation and execution of saccades (Wurtz & Optican, 1994).

Anticipatory Saccade Rate. Low anticipatory saccade rates would be expected for bilateral targets randomly presented for varying eccentricities (Benson, 2008; Hardwick et al., 2014), and that is what was found here. Only 1.21 % trials were characterised as anticipatory saccades, with 0.47 % in the GAP condition, 0.27 % in the CO and MO conditions, and 0.20 % in the BA condition. No marked main effects or interactions relative to group were found.

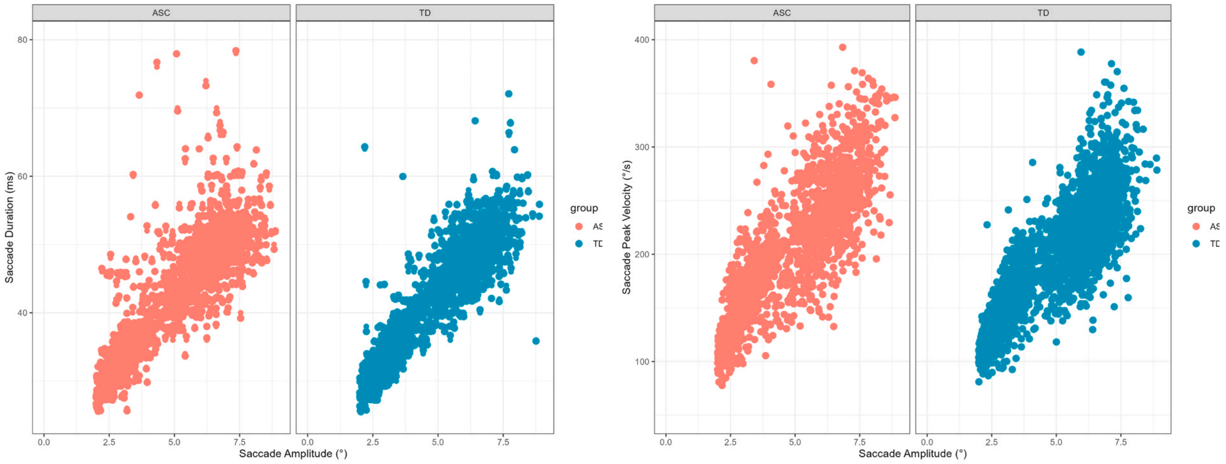
Gain. The LMM analysis revealed a significant effect of task ($F_{(3,\ 8.44)} = 45.39$, $p < 0.001$), suggesting the gain in the GAP task (0.75 ± 0.004) was the lowest compared to the other three tasks (BA = 0.80 ± 0.004, CO = 0.76 ± 0.004; MO = 0.77 ± 0.004). However, no main effect or interaction relevant to group reached significance.

Main Sequence. (1) Main sequence effect on saccade duration: A significant main effect of saccade amplitude was observed ($b = 4.64$, $SE = 0.09$, $t = 53.59$, $p < 0.001$), indicating that saccade duration increased with larger saccade amplitudes. However, no group difference or interaction reached statistical significance; (2) Main sequence effect on saccade peak velocity: A significant main effect of saccade amplitude was found ($b = 27.27$, $SE = 0.58$, $t = 46.90$, $p < 0.001$), demonstrating that saccade peak velocity exhibited an increment with increasing saccade amplitudes. No group difference or interaction was statistically significant. Further details of the main sequence relationships can be found in Fig. 2.

In summary, we analysed the express saccade rate, anticipatory saccade rate, gain and the main sequence effect across both groups. Only basic task effects were observed for the eye-movement measures, which is in line with previous eye-tracking evidence (Caldani et al., 2020; B. Fischer et al., 1997). There were no group differences, indicating intact oculomotor function in participants with ASC.

2.2.2. *Attentional disengagement analysis and results*

Valid saccade trials were identified based on the following criteria: (1) absence of blinks (resulting in the exclusion of 8.00 % of trials); (2) saccade amplitude exceeding 2° of visual angle (exclusion of 10.80 %); (3) saccade initiation within the central fixation region (within 2° visual angle from screen centre [960, 540], a pixel range from (860, 440) to (1060, 640); exclusion of 8.61 %); (4) saccade direction matching the target appearance direction (exclusion of 1.24 %); (5) absence of anticipatory saccades (SL < 80 ms) or excessively long latencies (SL > 1000 ms; exclusion of 1.68 %); and (6) saccade latencies falling within three standard deviations of the mean (exclusion of 1.29 %). Following this data screening procedure, analyses were conducted on a total of 4914 valid trials. There



(a) Main sequence relationship between saccade duration and saccade amplitude

(b) Main sequence relationship between saccade peak velocity and saccade amplitude

Fig. 2. The Main Sequence Relationship in Experiment 1.

was a significant difference in the number of valid trials between the groups, with TD children (61.79 ± 9.12) having significantly more valid trials than children with ASC (45.68 ± 14.12; $t_{(89)} = -6.51$, $p < 0.001$, Cohen's $d = -1.36$). Notably, as the analysis relied primarily on valid trials per participant, no participants were excluded from either Experiment 1 or Experiment 2.

Several parameters were examined, including SL (the latency between target appearance and the first saccade initiation, ms), disengagement cost (DC, consisting of CO-DC and MO-DC, calculated by subtracting BA-SL from CO-SL and MO-SL respectively, ms), and disengagement failure rate (FR, defined as the ratio of failed-disengagement trials to valid trials in the MO and CO tasks). LMM was utilized to examine SL differences, with group (ASC, TD) , task (MO, CO, BA, and GAP), target eccentricity (4°, 8°) and interactions serving as fixed factors. Furthermore, the random effects for participants and stimuli were incorporated into the model. For DC and FR analysis, due to the limited number of data points, RM-ANOVA was performed, with group (ASC, TD) as the between-group factor, while task (MO, CO) and eccentricity (4°, 8°) were considered within-group factors.

Saccade Latency. Results obtained from the LMM revealed significant main effects of group ($b = -20.05$, $SE = 9.82$, $t = -2.04$, $p = 0.044$) and task ($F_{(3,\ 10.74)} = 468.11$, $p < 0.001$). Further analysis demonstrated that children with ASC exhibited longer saccade latencies (238.50 ± 2.76 ms) compared to TD peers (227.97 ± 2.06 ms). There was also a gradient of SL across the four tasks. Specifically, the GAP condition (175.75 ± 2.12 ms) showed decreased SL, while the MO task (344.07 ± 4.19 ms) showed increased SL in comparison to CO (223.29 ± 3.05 ms) and BA (207.10 ± 2.00 ms) task conditions.

An interaction between group by task ($F_{(3,\ 4810.18)} = 12.46$, $p < 0.001$) demonstrated that ASC children in the MO task showed greater SL (369.54 ± 7.37 ms) than the TD children (329.27 ± 4.96 ms; $b = 44.60$, $SE = 11.04$, $t = 4.04$, $p = 0.001$). As expected, there was no significant task effect observed for either group in the traditional GOP (including CO, BA, and GAP sub-tasks). For more details from the LMM analysis, refer to Table 2. Fig. 3(a) displays the mean SL by task for both groups.

Disengagement Cost. Both task ($F_{(1,\ 89)} = 377.88$, $p < 0.001$) and eccentricity ($F_{(1,\ 89)} = 4.07$, $p = 0.047$) effects were found to be significant. More effort was needed to disengage in the MO task (147.53 ± 6.57 ms) compared to the CO task (18.59 ± 4.34 ms). Additionally, targets at 4° (90.24 ± 7.75 ms) resulted in a greater disengagement cost than targets at 8° (75.88 ± 6.87 ms).

A significant interaction between group and task ($F_{(1,\ 89)} = 6.92$, $p = 0.010$) showed that the difference was observed only in the measure of MO-DC ($t = 2.20$, $p = 0.030$, Cohen's $d = 0.46$), but not in CO-DC ($p > 0.05$), suggesting that the modified task is more sensitive to detect visual disengagement differences between groups. As expected, ASC children required more endogenous effort (167.37 ± 12.11 ms) to disengage from focused stimuli relative to TD children (134.17 ± 9.19 ms) in the MO task. The main effect of group and other interactions were not significant.

Failure Rate. Both task ($F_{(1,89)} = 9.91$, $p = 0.002$) and group ($F_{(1,89)} = 9.06$, $p = 0.003$) effects were significant. Children were less likely to disengage their attentional focus in the MO condition (8.91 % ± 1.40 %) compared to the CO condition (4.68 % ± 1.04 %). Furthermore, ASC children exhibited a lower likelihood (9.84 % ± 1.58 %) of initiating saccades toward targets compared to TD children (3.95 % ± 0.75 %).

2.3. Summary

In Experiment 1, we observed equivalent basic oculomotor function across ASC and TD children. This result supports the notion of intact fundamental eye-movement control in children with ASC, as previously reported for free viewing of movies (Avni et al., 2021) and for the main sequence task (Zhang et al., 2020). This important finding ensures that any group differences in attentional behaviour result from cognitive processing differences, and not from differences in oculomotor abilities.

Furthermore, we found that children with ASC had difficulty disengaging their focus from a central stimulus to the lateral target, with a significantly higher failure rate than the TD group. They also showed longer latencies and an increased disengagement cost compared to TD children in the MO task. These differences were absent when the classic GOP (including CO, BA and GAP sub-tasks) was adopted, and this finding aligns with our expectations, and with previously published evidence (Amestoy et al., 2021; J. Fischer et al., 2016; Wilson & Saldaña, 2019).

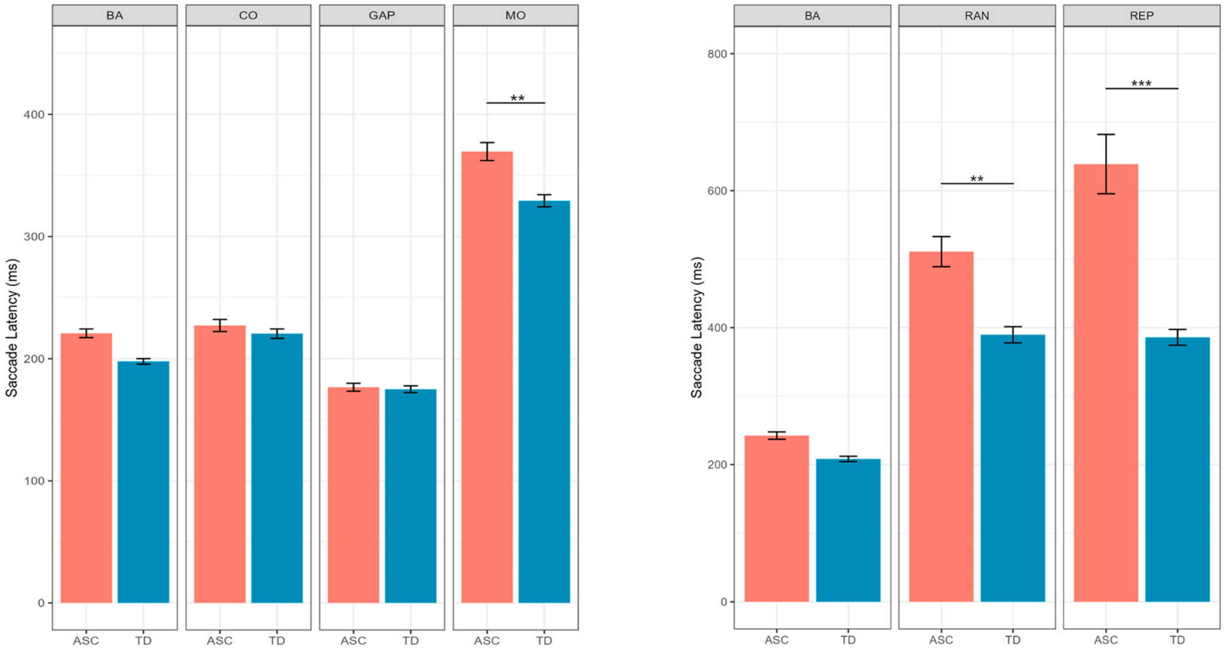
Simple static stimuli were employed in Experiment 1, but in the real world, stimuli are often dynamic, and ASC children show atypical processing in the context of repeated motion patterns, which is a characteristic of ASC diagnosis (American Psychiatric

Table 2

Fixed Effect Estimates (Group by Task) on Saccade Latency in Experiment 1.

	b	SE	t	p
TD vs. ASC	−20.05	9.82	−2.04	0.044
GAP vs. BA	−35.32	3.51	−10.07	< 0.001
CO vs. BA	15.19	6.66	2.28	0.068
MO vs. BA	141.35	6.78	20.86	< 0.001
MO vs. CO	126.17	3.81	33.08	< 0.001
GAP vs. CO	−50.50	6.64	−7.60	< 0.001
MO vs. GAP	176.67	6.76	26.13	< 0.001
MO: ASC vs. TD	44.60	11.04	4.04	0.001
CO: ASC vs. TD	9.03	10.75	0.84	1.000
BA: ASC vs. TD	24.61	10.71	2.30	0.139
GAP: ASC vs. TD	1.93	10.67	0.18	1.000

Note. ASC = autism spectrum condition; TD = typically developing; MO = modified-overlap; CO = classic-overlap; BA = baseline.



(a) Experiment 1 (b) Experiment 2

Fig. 3. Saccade Latencies across ASC and TD Groups in Experiment 1 and Experiment 2. Note. ASC = autism spectrum condition; TD = typically developing; BA = baseline; CO = classic-overlap; MO = modified-overlap; REP = repetitive movement; RAN = random movement.

Association, 2013). In Experiment 2, we investigated attentional disengagement from dynamic motion patterns, and directly compared REP motion versus RAN motion for both MO and BA tasks from Experiment 1.

3. Experiment 2

3.1. Methods

3.1.1. Participants

A power analysis was conducted, akin to Experiment 1. Specifically, for Experiment 2′s RM-ANOVA design—where group (ASC, TD) was the between-subjects factor, and both task (MO, BA) and motion type (REP, RAN) were within-subject factors—a minimum of 36 participants (18 per group) was required to detect the interaction effect.

A cohort of 52 young participants took part in the current experiment. Among them, 26 ASC children ($M_{\text{age}} = 68.07$ months) were recruited from the same Autism Research Service Centre in Tianjin. In addition, 26 TD children ($M_{\text{age}} = 72.20$ months) were recruited from the same three kindergartens as in Experiment 1. All ASC children were clinically diagnosed with autism according to DSM-5 (American Psychiatric Association, 2013), and the AQ scale (Auyeung et al., 2008) was adopted to validate the diagnosis. Notably, children with ASC exhibited significantly higher AQ scores than TD children ($t_{(50)} = 6.00$, $p < 0.001$). Consistent with Experiment 1, all participants' age, gender, VIQ, PIQ and FSIQ were group-matched. Written consent was obtained from the participants' parents before the experiment. See Table 1 for participant characteristics.

3.1.2. Stimulus and apparatus

All dynamic stimuli were created using Macromedia Flash, and these were presented against a black background with a display size of 1920 × 1080 pixels. A grey circle (0.8 × 0.8°) served as the motion stimuli. Two types of motion were employed: REP movement and RAN movement. These dynamic stimuli were confined within a 6° × 3° central square region and moved at a comparable speed. As in Experiment 1, a solid grey square was used as the peripheral target, positioned at 9° in the right or left side of the visual field randomly. In total, 32 moving stimulus videos were created. These were equally divided between the two movement patterns, and each video lasted for 8000 ms.

In Experiment 2, the eye-tracking apparatus and parameter settings remained consistent with Experiment 1.

3.1.3. Procedure

The calibration process for Experiment 2 closely mirrored that of Experiment 1. Formal trials commenced with the central fixation presented against a black background for 500–800ms. In the MO task, the foveal stimulus (circle), which included the REP movement or RAN movement, overlapped with the presentation of the peripheral target (square) for 8000 ms. The 8000 ms video was presented for its full duration in every MO trial. Conversely, during the BA task, the peripheral target was presented in isolation for 1500 ms. All trials concluded with a blank screen displayed for 500 ms. See Fig. 4 for trial sequences.

Experiment 2 consisted of a total of 48 formal trials, comprising 16 BA trials and 32 MO trials (16 REP and 16 RAN trials). These trials were presented in one block with a pseudorandom order. Children were provided with clear instructions to fixate on the foveal stimulus and look at the target square when it appeared.

3.1.4. *Statistical methods*

Consistent with the criteria applied in Experiment 1, we excluded the following eye-movement trials from the analysis: (1) trials involving blinks (7.62 % of the data); (2) trials with saccade amplitudes less than 2° (22.57 %); (3) trials where the saccade initiation was not within the central fixation region (outside 2° visual angle from screen centre [960, 540], a pixel range from (860, 440) to (1060, 640); 2.21 %); (4) anticipatory saccades (SL $<$ 80 ms) or abnormally long saccades (SL $>$ 1000 ms; 0.76 %); (5) trials with incorrect saccade directions (4.37 %); and (6) trials with SL falling outside three standard deviations from the mean (0.92 %). Following this data screening procedure, the final analysis was conducted on 1535 valid trials. There was a significant difference in the number of valid trials between the two groups of young children, with TD children having significantly more valid trials (34.85 ± 3.64) than children with ASC (24.19 ± 7.53; $t_{(50)} = -6.50$, $p < 0.001$, Cohen’s $d = -1.80$).

Following the approach of Experiment 1, we first analysed SL and DC. The measure of failure rate was unnecessary for inclusion in this analysis since participants were able to disengage their focus within 8000 ms. We first analysed the SL for group and task, followed by analysis of the SL for group by stimulus type in the MO task, using the LMM in line with Experiment 1. For DC, an RM-ANOVA was computed with the independent factors of group and motion type.

Following initial analysis, we conducted further analyses using the data from the two experiments to explore factors associated with delayed attentional disengagement in children with ASC. First, we analysed dwell time (measured in milliseconds as the cumulative duration of fixations, saccades, and visits within the area of interest) for both experiments. This served as a measure of attentional engagement with the foveal stimuli, enabling us to investigate the potential link between engagement and disengagement. The area of interest (AOI) for the foveal (static/dynamic) stimuli was defined as 60 × 60 pixels in Experiment 1 and 400 × 400 pixels in Experiment 2. Second, we hypothesized an association between AQ scores and our disengagement measures. Accordingly, we also examined the relationship between attentional disengagement performance (e.g., SL, DC) and autistic traits (indexed by AQ scores) across both experiments.

3.2. *Results*

3.2.1. *Saccade latency*

Analysis of LMM for group and task: A main effect of task ($b = 377.41$, $SE = 17.83$, $t = 21.17$, $p < 0.001$) showed that participants produced significantly greater SL in the MO condition (461.55 ± 12.06 ms) compared to the BA condition (223.79 ± 3.30 ms). Moreover, a significant interaction ($b = -191.89$, $SE = 25.29$, $t = -7.59$, $p < 0.001$), revealed that ASC children (589.07 ± 28.01 ms) required more voluntary processing to disengage from central stimuli compared to TD children (387.31 ± 8.34 ms) in the MO task ($b = 227.40$, $SE = 41.40$, $t = 5.49$, $p < 0.001$), and this difference was absent in the BA task. No group effect was observed.

Analysis of LMM for group and motion type in the MO task: Both the main effects of group ($b = -156.48$, $SE = 37.54$, $t = -4.17$, $p < 0.001$) and motion type were significant ($b = 254.95$, $SE = 15.78$, $t = 16.16$, $p < 0.001$). Specifically, ASC children demonstrated

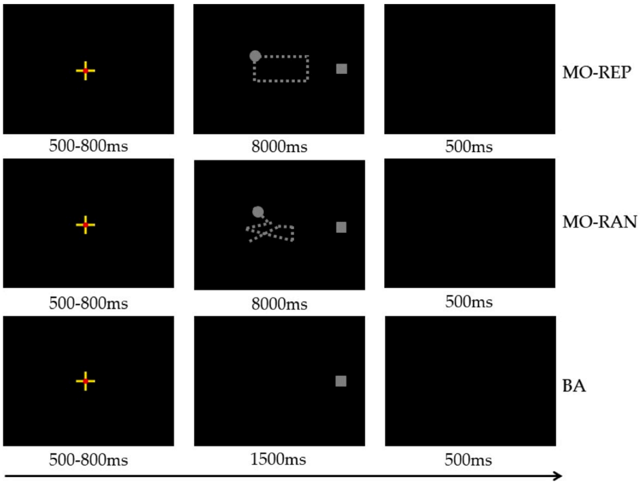


Fig. 4. Experimental Procedure in Experiment 2. Note. MO = modified-overlap; BA = baseline; REP = repetitive movement; RAN = random movement.

delayed disengagement (589.07 ± 28.01 ms) compared to TD children (387.31 ± 8.34 ms) in the MO task. Furthermore, children exhibited prolonged disengagement from REP stimuli (481.35 ± 18.69 ms) compared to RAN stimuli (432.42 ± 11.33 ms) and a significant interaction ($b = -136.82$, $SE = 31.55$, $t = -4.34$, $p < 0.001$), indicated that there were differences in disengaging between REP (638.77 ± 43.30 ms) and RAN motion (510.92 ± 21.99 ms) in the ASC group ($b = -86.78$, $SE = 26.30$, $t = -3.30$, $p = 0.013$), whereas TD children displayed similar disengagement behaviours across both REP (385.76 ± 11.56 ms) and RAN motion types (389.51 ± 11.80 ms), with $p > 0.05$. Fig. 3(b) and Table 3 display the mean SL and LMM results in Experiment 2 respectively.

3.2.2. Disengagement cost

Disengagement cost is calculated by subtracting BA-SL from MO-SL. A significant group difference ($F_{(1,\ 48)} = 10.73$, $p = 0.002$) showed that children with ASC (377.17 ± 46.46 ms) required more effort to disengage from the foveal stimuli than TD children (186.03 ± 11.36 ms). No other significant main effects or interactions were observed. However, there were numerical differences, which showed that the REP cost (413.80 ± 83.10 ms) was greater than the RAN cost (340.54 ± 42.36 ms) in the ASC group, whereas a similar cost across REP (181.67 ± 15.47 ms) and RAN motion stimuli (190.39 ± 16.89 ms) was noted for TD children.

3.2.3. Associations with attentional engagement (Dwell Time)

In Experiment 1, we found that the dwell time for the stimulus requiring disengagement in children with ASC ($M = 493.82$ ms, $SE = 11.26$ ms) was significantly longer than that in TD children ($M = 428.15$ ms, $SE = 8.88$ ms), indicating that children with ASC had a deeper depth of processing (attentional engagement) of the central static stimulus ($t = 4.54$, $p < 0.001$, Cohen's $d = 0.29$). We further explored the relationship between this metric and the participant's SL in both groups of children. The results showed a significant positive correlation between the two, $r = 0.501$, $p < 0.001$.

Similarly, analysis of Experiment 2 also yielded consistent findings. Children with ASC ($M = 3132.68$ ms, $SE = 99.96$ ms) showed longer processing time (dwell time) on the dynamic stimulus requiring disengagement than TD children ($M = 1073.81$ ms, $SE = 45.35$ ms; $t = 21.30$, $p < 0.001$, Cohen's $d = 1.54$). This deeper attentional processing (longer dwell time) was significantly correlated with the delay in attentional disengagement (longer saccade latencies) ($r = 0.463$, $p < 0.0001$). Therefore, the deeper the attentional processing of the central (requiring disengagement) stimulus, the more likely delayed attentional disengagement will be exhibited.

3.2.4. Associations with autistic traits (AQ Scores)

No significant correlation was observed between attentional disengagement measures and AQ scores in Experiment 1 ($ps > 0.05$). However, in Experiment 2, AQ scores were significantly correlated with SL in the MO task ($r = 0.412$, $p = 0.002$). Significant correlations were also found across both repetitive motion ($r = 0.410$, $p = 0.003$) and random motion ($r = 0.409$, $p = 0.003$) for SL. Furthermore, AQ scores showed a significant correlation with DC overall ($r = 0.397$, $p = 0.004$), as well as specifically for repetitive motion ($r = 0.396$, $p = 0.004$) and random motion ($r = 0.391$, $p = 0.005$). Notably, no significant correlation was found for SL in the BA task ($p > 0.05$).

3.3. Summary

Consistent with the results of Experiment 1, ASC children exhibited a generalized delayed disengagement pattern compared to TD children in the MO task, with increased SL and more endogenous time cost to disengage relative to TD children. Furthermore, the observed attentional disengagement differences were significantly correlated with attentional engagement (measured by dwell time) and autistic traits (indexed by AQ scores) across both experiments. Specifically, greater foveal processing/engagement appeared to further delay their ability to disengage attention. Additionally, children with higher AQ scores exhibited poorer attentional disengagement from dynamic stimuli, as evidenced by increased SL and/or DC.

A novel finding showed that ASC children displayed delayed visual disengagement (longer SL) for the REP motion compared to the RAN motion, and this effect was absent in the TD group. This effect was also observed (numerically) for the disengagement cost analysis. These findings align with previous research using a visual-preference paradigm, and support the idea that children with ASC attend more to REP motion compared to RAN motion (Li et al., 2021; Wang et al., 2018).

4. General discussion

The primary objective of the present study was to investigate attentional disengagement differences in children with ASC, for static (Experiment 1) and dynamic (Experiment 2) stimuli. We initially evaluated fundamental oculomotor function across both groups to

Table 3
Fixed Effect Estimates (Group by Motion Type) on Saccade Latency in Experiment 2.

	b	*SE*	*t*	*p*
TD vs. ASC	−156.48	37.54	−4.17	< 0.001
REP vs. RAN	254.95	15.78	16.16	< 0.001
ASC: REP vs. RAN	−86.78	26.30	−3.30	0.013
TD: REP vs. RAN	3.74	19.70	0.19	1.000

Note. ASC = autism spectrum condition; TD = typically developing; REP = repetitive movement; RAN = random movement.

ascertain that any subsequent attentional differences were not attributed to basic eye-movement differences in ASC. Following this, and in line with our initial hypothesis, we revealed a delayed endogenous disengagement in the ASC group compared to the TD group across Experiment 1 and Experiment 2. This was exclusively evident in the adopted MO task. Moreover, in Experiment 2, we observed a distinct modulation effect of poorer visual disengagement in ASC in the presence of dynamic REP stimuli. Notably, this difference was absent in the TD group, highlighting a unique characteristic of attentional processing in ASC.

Previous evidence has reported intact visual disengagement across toddlers (J. Fischer et al., 2016), older children (Caldani et al., 2020; J. Fischer et al., 2014; McLaughlin et al., 2021; Wilson & Saldaña, 2019), adolescents and adults with ASC (Kawakubo et al., 2004; Skripkauskaite et al., 2021; Zalla et al., 2018), for both static and dynamic stimuli (Sabatos-DeVito et al., 2016; Wilson & Saldaña, 2019). However, our findings consistently suggest that there are voluntary (endogenous) disengagement problems in young children with ASC.

In Experiment 1, using simple geometric stimuli, we observed weaker visual disengagement in ASC children for the MO task. Specifically, children with ASC took longer to move their eyes towards the lateral targets in the presence of central distractors compared to TD children. In Experiment 2, using dynamic stimuli, we again observed poorer visual disengagement in ASC for the MO task. Specifically, ASC children took longer to move their eyes towards the lateral targets in the presence of dynamic central distractors compared to TD children. Two things are important to be discussed here.

First, the classic GOP paradigm, with its three different sub-set conditions (BA, CO, and GAP), actually seems to mask any group disengagement differences and we have discussed the reasons for this in our previous paper (Zhou et al., 2022). To recapitulate briefly, the reason for the failure to observe group differences in disengagement using traditional GOP is because in the CO task (a major task to explore attentional disengagement), the foveal stimulus is presented for a long time in isolation, which means it has been fully processed prior to the target display. Therefore, under those circumstances, the saccade latencies for the CO condition are equivalent to those for the BA condition for both groups.

Second, our MO task prevents any preprocessing of the central stimulus prior to the target presentation, which results in the observed group differences in voluntary disengagement. These differences are apparent for both static and dynamic simple stimuli, and are absent for the traditional GOP paradigm. These findings validate and expand recent research (Zhou et al., 2022), in which it was found that ASC children had more difficulty and lower efficiency to endogenously disengage from both circumscribed-interest objects (e.g., helicopters) and non-circumscribed-interest objects (e.g., plants) than their TD peers using the MO task.

A further interesting finding that merits discussion is the observation that repeated motion central stimuli are more difficult to disengage from compared to random motion central stimuli exclusively for the ASC group. This modulation effect fits with findings from visual-preference evidence (Li et al., 2021; Wang et al., 2018), where increased looking time to REP motion compared to RAN motion was observed in the autistic group. It has been suggested that ASC children may find REP items more engaging and comforting, because this predictability in the motion provides them with a sense of familiarity, and helps them to cope with sensory processing difficulties or sensory-seeking behaviours (Dichter et al., 2012; Turner, 1999). It has also been proposed that REP motion could serve as a source of sensory stimulation and self-regulation, reducing anxiety and promoting a sense of control in one’s own surroundings (Baribeau et al., 2020; Rodgers et al., 2012). In our daily life, it is common to observe ASC children staring at repetitive spinning fans or gazing at rotating wheels for a prolonged period (Mooney et al., 2006; Pierce et al., 2011). Whilst engaged in these behaviours, children rarely orient their attention to other meaningful stimuli, especially stimuli of a social nature (Miller et al., 2021). Therefore, ASC children may fail to respond to opportunities in the environment to acquire joint attentional abilities (Muratori et al., 2019), auditory word recognition (Venker, 2017) and social cognition skills (Elison et al., 2013; Keehn et al., 2021).

Our study also enables us to identify or rule out some of the factors that might be thought to underpin atypical attentional disengagement in ASC. For example, it has been suggested that atypical attentional disengagement may be directly underpinned by dysfunctional attentional shifting in ASC. However, the data from the two experiments in the current study revealed strikingly similar performance between ASC and TD children in BA task conditions. This suggests that ASC children retain intact attentional shifting abilities, a finding robustly supported by prior research (e.g., Caldani et al., 2020; Landry & Bryson, 2004; van der Geest et al., 2001; Zhou et al., 2022, 2024). The current study also identified that factors such as the lack of foveal stimulus pre-processing and repetitive motion exacerbate atypical disengagement in ASC, and the data from the current study also enable us to show that over-engagement or deeper processing of the foveal stimuli influences visual disengagement performance.

A post-hoc analysis of dwell time for foveal stimuli across both experiments showed that dwell time in ASC children was significantly longer for foveal (static and dynamic) stimuli compared to TD children. The dwell time data also correlated positively with delayed disengagement, as measured by SL, in both experiments. Thus, deeper processing (over-engagement) of central stimuli appears to prolong attentional disengagement, and this correlational analysis highlights the relationship between "engagement" with and "disengagement" from foveal stimuli in the current study.

Additionally, we found an association between autistic traits and atypical attentional disengagement performance in children with ASC under dynamic (Experiment 2) stimulus conditions which showed significant correlations between AQ scores and SL for both stimulus motion types within the MO tasks, as well as with disengagement costs. This observation may support Keehn (2021) proposition that dynamic stimuli, due to their inherent salience, might elicit stronger attentional engagement in young children with ASC compared to static stimuli. Consequently, attentional disengagement differences could be more pronounced or discernible in children exhibiting higher autistic traits, and, dynamic stimuli might be more effective for differentiating individuals with high versus low autistic traits, or for identifying individuals with ASC. This could potentially explain the predictive validity observed in prospective research using dynamic stimuli with high-risk autism infants (e.g., Bryson et al., 2018). However, it is crucial to acknowledge that attentional disengagement delays in children with ASC are likely multifactorial in origin. While the current study investigated a subset of potential contributing factors, further research is warranted to comprehensively elucidate the underlying causes of attentional disengagement deficits in autistic children.

We acknowledge some of the limitations to the current study. First, the current study adopted the AQ as a measure for autistic traits. While the AQ effectively captures levels of autistic-like traits and can assist in differentiating between autistic and non-autistic children (Auyeung et al., 2008), it would have been preferable to utilize additional observational measures, such as the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2) to gain a more comprehensive understanding of the characteristics of children with autism. Given that the gold standard diagnostic measure for autism (e.g., ADOS-2) has not been universally implemented in China, future research should aim to employ these gold standard observation methods to validate clinical diagnosis of children with ASC. Second, participant recruitment was restricted to high-functioning children with ASC (IQ > 70), to ensure adequate matching with TD children on this cognitive variable. This means that we cannot say whether the attentional disengagement findings from the current study apply to other subgroups of children on the spectrum, or to children with other forms of neurodevelopmental disorders, and these questions also merit further investigation.

5. Conclusion

The purpose of this study was to investigate the attentional disengagement performance of children with ASC in response to static and dynamic stimuli, and it was found that ASC children exhibit delayed attentional disengagement. These results challenge the prevailing notion of intact disengagement in ASC and offer insights into potential reasons for previously reported null findings regarding group differences. Overall, the current study provides evidence to show intact oculomotor function coupled with voluntary disengagement difficulties for static and dynamic simple stimuli in young children with ASC. The findings, for the repeated motion stimuli, may relate to the diagnostic criteria of increased repetitive behaviours in ASC. Furthermore, the findings show how behaviours characteristic of one of the core diagnostic criteria (repetitive interest and behaviours) can potentially impact the development of abilities characteristic of the other core (social communication) diagnostic criteria.

Ethics approval

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).

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CRediT authorship contribution statement

Valerie Benson: Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Li Zhou:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation.

Declaration of Competing Interest

We have no conflict of interests to disclose.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.reia.2025.202686.

Data availability

Data will be made available on request.

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