Journal of Cognitive Psychology

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

Attentional processing of preserved face and scrambled face distractors in preschool children with autism spectrum condition

Li Zhang, Li Zhou, Lichao Kang, Yuening Xu, Hong Jiang & Valerie Benson

JOURNAL OF COGNITIVE PSYCHOLOGY
https://doi.org/10.1080/20445911.2024.2314972

Attentional processing of preserved face and scrambled face distractors in preschool children with autism spectrum condition

Li Zhang[a], Li Zhou[b], Lichao Kang[c], Yuening Xu[c], Hong Jiang[d] and Valerie Benson[e]

[a]Jiangsu Provincial University Key Lab of Child Cognitive Development and Mental health, Yancheng Teachers University, Yancheng, People's Republic of China; [b]Faculty of Education, East China Normal University, Shanghai, People's Republic of China; [c]Faculty of Psychology, Tianjin Normal University, Tianjin, People's Republic of China; [d]Tianjin Siteng Rehabilitation Centre for Autistic Children, Tianjin, People's Republic of China; [e]School of Psychology and Humanities, University of Central Lancashire, Preston, UK

ABSTRACT
The current study investigated attentional processing of preserved neutral face and scrambled neutral face distractors at both involuntary and voluntary orienting levels in children with and without autism spectrum condition (ASC). The findings suggest similar influences of face configuration on reflexive orienting in both groups but reveal group differences in voluntary disengagement from face-related distractors. The ASC group exhibited difficulties in disengaging from the central neutral faces, and the TD group showed longer latencies for scrambled faces. These group differences suggest inefficiency in adopting a global face processing strategy at the voluntary attentional level in ASC. We discuss how the observed effects might impact upon the development of social communication skills in ASC.

ARTICLE HISTORY
Received 23 March 2023
Accepted 11 December 2023

KEYWORDS
ASC; face and non-face distractors; reflexive orienting; voluntary orienting; face processing style

Introduction

Autism spectrum condition (ASC) is characterised by social and communicative deficits coupled with repetitive and stereotypical behaviours (the Fifth Version of Diagnostic and statistical manual of mental disorders, American Psychiatric Association, 2013). Social orienting deficits have been extensively investigated and identified as one of the most important symptoms and pathologies of this condition (Chevallier et al., 2012; Dawson et al., 1998; Guillon et al., 2016; Klin & Jones, 2008). Atypical social orienting has been reported in post-hoc observations of reduced orientation to faces for participants with ASC in social interactions in early life (Chawarska et al., 2013; Swettenham et al., 1998), and also in findings that report reduced numbers of fixations devoted to faces presented in isolation (Jones et al., 2016) or in social scenes in this population (e.g. Freeth et al., 2010; Riby & Hancock, 2009; Rigby et al., 2016; Sumner et al., 2018). It has been suggested that these atypicalities in social orientation could lead to inadequate processing of and responses to important social cues in external environments, and thus could offer an account for abnormalities in higher-level social cognition in ASC, such as mentalising abilities and face processing (Chevallier et al., 2012).

The two attentional orienting systems, voluntary and involuntary, play an important role in human visual attention (Posner, 1980; Posner, Snyder, & Davidson, 1980). Voluntary attention is endogenous and top-down, and thus it operates during intentional tasks. Involuntary or exogenous attention is, in contrast, reflexive in nature. It operates in a transient way to capture and draw attention to possible sudden or significant stimuli in the environment very quickly. Previous studies have shown that facial information can exert an influence on both the voluntary and involuntary attentional processes (García-Blanco et al., 2017; Leppänen, 2016). At the behavioural level, evidence of face-related effects on involuntary attention include the findings of greater proportions of first saccades or shorter saccade latencies directed towards faces (versus non-faces, e.g. Crouzet et al., 2010; Elsabbagh et al., 2013), and the findings of faster reaction times to detect a

CONTACT Valerie Benson vbenson3@uclan.ac.uk School of Psychology and Humanities, University of Central Lancashire, Preston PR1 2HE, UK

target correctly cued by facial stimuli (e.g. Theeuwes & Stefan, 2006) in button-pressed tasks. In contrast, facial effects on voluntary attention are usually evidenced by greater distraction which leads to increased reaction times to detect a target (Weaver & Lauwereyns, 2011), or a capacity to hold attention which results in longer fixation times on faces (Leppänen, 2016). However, these typical effects may not be operating the same way in the ASC population.

In relation to ASC, numerous studies have reported typical face orienting at the involuntary level in ASC. For example, participants with ASC respond faster to faces, or to a target spatially cued by faces compared to non-facial stimuli in reaction time studies, and responses are equivalent to those reported for typically developing (TD) participants (Akechi et al., 2015; Moore et al., 2016; Shah et al., 2013). It has also been shown that an ASC group make high proportions of first eye movements to faces, comparable with a TD group (Del Bianco et al., 2018; Elsabbagh et al., 2013; Fischer et al., 2014; Fischer et al., 2016; Hendry et al., 2018; Sumner et al., 2018; Wilson et al., 2010). These findings suggest evidence of unimpaired attentional orienting to faces in ASC at the reflexive level, and they contradict the prevailing theory of social orienting deficits in ASC (Johnson, 2014).

However, social attention differences observed in ASC could still result from inefficient voluntary attentional orienting and engagement processes (Elsabbagh et al., 2013; Guillon et al., 2014; Johnson, 2014). For example, individuals with ASC fail to allocate attention to social scenes depending on specific instructions (Benson et al., 2009). There is also evidence from neuroimaging data to suggest that the presentation of faces interferes with the execution of cognitive control in ASC (Dichter & Belger, 2007), and some studies report findings of prolonged attention to faces in infants and toddlers with ASC in visual search tasks (Elsabbagh et al., 2013; Hendry et al., 2018). Studies that have examined visual habituation to faces in ASC have also found prolonged looking time to faces (Webb et al., 2010). This atypical attentional performance in ASC could reflect an inefficient processing of faces at the voluntary level, possibly pointing to the commonly reported detail-focused processing style in this population (Behrmann et al., 2006; Happé & Frith, 2006). It is also thought that this "sticky attention" for faces in ASC could delay the disengagement speed from fixated faces and thus lead to inefficient detection of new stimuli.

In everyday interaction voluntary attentional modulation is essential. Flexible orientation and attentional shifting is required to track ongoing social events or information, and, efficient attentional disengagement, which is fundamental to voluntary attentional modulation, requires the execution of voluntary control (Colombo & Cheatham, 2006; Hopfinger et al., 2000). However, most investigations of social orientation in ASC have focused on visual allocation patterns using a passive free viewing task (a paradigm whereby participants have no specific task but attend to the display screen at their free will), with little emphasis on how attentional control might operate within a social context (DiCriscio et al., 2016). Therefore, a focus on the investigation of social attention in ASC, under voluntary control, is important.

One aim of the current study is related to whether the ASC group exhibit disengagement atypicalities from centrally presented faces, when the task requires a shift in visual focus to a peripheral location as quickly as possible. A further interest is to investigate whether any modulating effects on voluntary attentional processing of faces in ASC could reflect a difference in processing style or strategy. According to the "sticky attention" hypothesis presented earlier, prolonged attention to faces could reflect a preference for feature-based processing style in this population. Evidence relating to the second aim could add to our understanding of cognitive mechanisms underlying disengagement atypicalities in ASC. Previous studies have pointed to an intact ability to attend to faces reflexively in many situations, and it has been proposed that attentional deficits in face processing for ASC are more related to voluntary processes. However, few studies have directly compared attentional processing of faces at both the voluntary and involuntary levels in this population in the same study, and this was the final aim of the current study.

The current study addressed the above questions by adopting the remote distractor paradigm (RDP, Walker et al., 1997). In this paradigm, participants are asked to look to a target and to ignore any distractors presented with this target. Saccade latencies (time needed to initiate the first saccade to the target) are found to decrease as the eccentricities of distractors increase, and centrally presented distractors have been shown to produce the longest latencies in both typical and ASC individuals (Zhang et al., 2020). Findings have also revealed that children with ASC take longer to disengage from centrally fixated distractors of simple shapes (Zhang et al., 2020) or from distractor faces showing negative emotions (Zhang et al., 2021). Furthermore, all children, regardless of diagnosis, make very high percentages of saccadic errors to both parafoveal and peripheral distractors. Thus, this paradigm works very well in young children, and hence should allow the investigation of interference from facial and non-facial distractors on reflexive (errors) and voluntary (latencies) attentional mechanisms in ASC and TD groups. Reflexive attentional orienting in the paradigm is defined as a complete failure to ignore a distractor (simultaneously presented with the target) which is reflected by the first eye movement being executed towards the distractor (error) instead of the target. Voluntary attentional orienting in the paradigm is defined as the ability to suppress a reflexive eye movement being executed towards the distractor, which is reflected in the first eye movement being executed towards the target (correct response) and the time taken to do this (latency) reflects the impact of the distractor on the voluntary attentional system.

Experiment 1 investigated the distractor effects of facial configuration (face-like shape patterns) in the RDP and non-face-like shape pattern distractors were adopted as the control condition. Compared to non-face-like patterns, face-like patterns attract more attention in the TD population (Guillon et al., 2016; Johnson et al., 1991), and this finding suggests typical participants tend to perceive faces as a whole, reflecting global processing for the TD group. In Experiment 1, we predicted that the TD group would show a larger interference effect from face-like distractors compared to non-face-like distractors. We also predicted that this effect would be either absent or reduced in the ASC group if they do not adopt a global processing style for faces. Moreover, according to previous findings, we also predicted that any atypicalities in the ASC group would be more obvious at the voluntary attention level (latencies), compared to the involuntary attention level (errors).

Experiment 1

Methods

Participants

Seventeen children (1 female) diagnosed with ASC with age ranging from 4.5 to 7 years old and 19 (5 females) TD children with age ranging from 4.5 to 6 years, recruited from the kindergartens in Tianjin, China volunteered to participate in the study. No history of brain damage or neurodevelopmental atypicality was reported for the TD children by their parents. All participants had normal or corrected-to-normal vision.

All the ASC children were officially diagnosed with ASC by at least one experienced clinician, and these diagnoses were in accordance with the ASC criteria listed in the Fifth Edition of the DSM (APA, 2013). Given very limited use of the Autism Diagnostic Observation Schedule and Autism Diagnostic Interview in mainland China, the Chinese version of the Autism Spectrum Quotient: Children version (AQ-child; Auyeung et al., 2008) was applied to all participants by either parents or teachers as a means to validate the clinical diagnoses. Results showed that children with ASC scored higher (above the cut-off of 76) on ASC traits and behaviours relative to TD children, $t = 5.22$, $p < 0.001$.

Three different profiles of Intelligence Quotient (IQ), including Verbal IQ (VIQ), performance IQ (PIQ) and full-scale IQ (FSIQ), were measured in all children using the Chinese version of the Wechsler Preschool and Primary Scale of Intelligence: Fourth Edition. Both groups scored higher than 90 and were matched on the VIQ, PIQ and FSIQ, $ts < 1.90$, $ps > 0.05$. Chronological age (CA) was higher in the ASC group, $t = 5.26$, $p < 0.001$ (see Table 1 for details of AQ, IQ scores and CA for both groups).

The procedures of the current study were approved by the Ethical Committee of Tianjin Normal University and were conducted in accordance with the Declaration of Helsinki (1964). Prior to the study, the parents of all participants were informed of all the procedures and gave consent to the participation of their children.

Apparatus

In Experiment 1, an EyeLink Portable Duo (S.R. Research Ltd, Canada) eye-tracker was utilised to collect the eye movement data, with a sampling

Table 1. Demographic data (mean ± SD) of the ASC and TD groups on age, IQ and AQ scores in Experiment 1.

	ASC ($n = 17$)	TD ($n = 19$)	t	p
Age (months)	76.94 (6.37)	67.16 (4.76)	5.26	< **0.001**
VIQ	110.65 (16.62)	108.47 (7.71)	0.51	0.61
PIQ	105.35 (20.87)	116.95 (16.02)	−1.88	0.07
FSIQ	107.59 (17.77)	112.00 (9.41)	−0.95	0.35
AQ	85.18 (18.37)	58.89 (11.36)	5.22	< **0.001**

rate of 1000 Hz. A 19-inch DELL monitor with a resolution of 1024 × 768 pixels with a refresh rate of 75 Hz was used for stimuli presentation. During the experiment participants placed their heads in a chin rest, to maintain head stability.

Materials

The target was an oval outline with a central black square. The size of the target was 4.35° × 5.42° (135 × 158 pixels) at 65 cm viewing distance. Face-like patterns and non-face-like patterns were selected as the distractors. Both distractors presented the same inner black shapes (two circles, one triangle and one rectangle). In face-like distractors the inner shapes formed a facial configuration with the circles as the eyes, the triangle as the nose, and the rectangle as the mouth. However, for the non-face distractor the inner shapes were allocated to the middle vertical line symmetrically. All target and distractor stimuli were greyscale oval shapes and distractors were the same overall size as the target. Stimuli examples are shown in Figure 1.

The target appeared in isolation at an eccentricity of 5° or 10° on the left side or the right side of the display, or, it was presented simultaneously with a distractor located either at the centre of the display, or in the parafoveal (5°) or peripheral region (10°) from the display screen centre. In the central distractor condition, the target had four possible positions, namely 5° or 10° away from the central point of the screen on both sides of the display. In the parafoveal and peripheral conditions, the distractor and the target were presented on the opposite side of the display to each other. All stimuli were displayed on a black background. In total, there were 112 trials for each distractor type block, and each block included 28 single target trials and 84 distractor trials.

In order to determine the power of the current design, we adopted the method from Westfall (2015). In this method, the participant number in each group was set to be 17, which was based on the smaller ASC group. Moreover, an average effect size of $d = 0.45$ was utilised for the estimation. As a result, the range of current power values, including effects of the distractor type, distractor position and all the interactions, were from 0.87 to 0.99, which were greater than the recommended level of 0.8. However, the power of the group effect was 0.72, lower than the required level. According to prior predictions, the current study focused more on the within group differences among different distractor types or positions, instead of the gross group effect as a whole. Therefore, Experiment 1 had good power to indicate statistically meaning effects of average size.

Procedure and eye movement recording

In a pre-test, participants were shown the example stimuli on the display screen and were

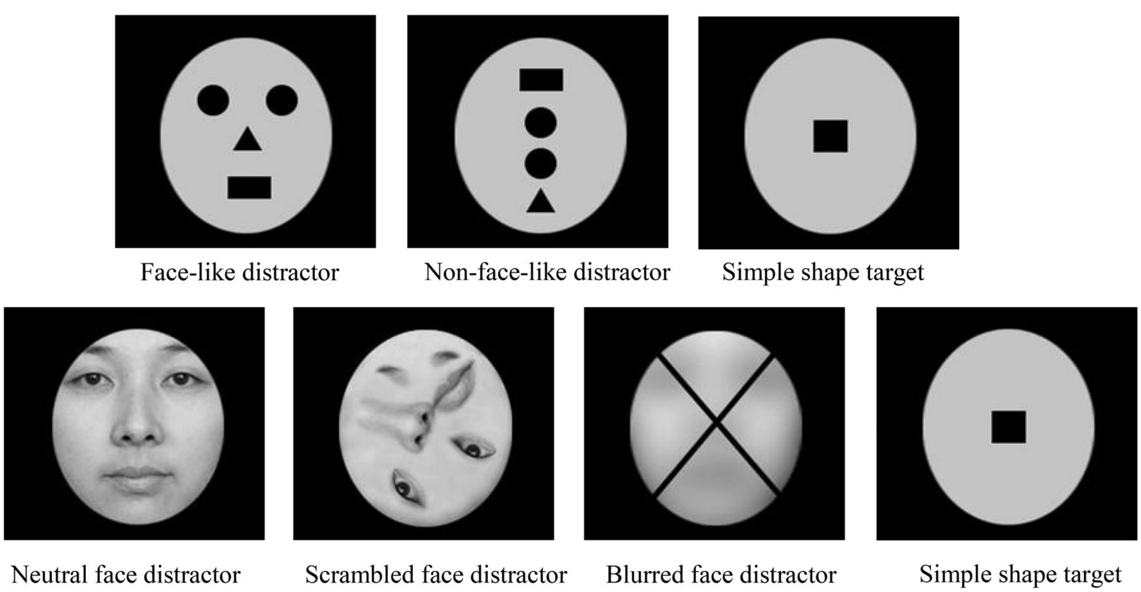

Figure 1. Face distractor example, non-face distractor example and simple shape target used in Experiment 1 (top) and Experiment 2 (bottom).

asked to verbalise what they were required to do, or to point out the target they should look to and the distractor to be ignored. Following validation of an understanding of the task, RDP example trial sequences were presented in slides and participants were required to make a selective eye movement to the target. The children also took part in a practice session on the eye tracker to familiarise them with this procedure prior to testing.

Formal test procedures were the same in all experiments. In the formal test, a three-point-calibration was run first to record eye position by asking participants to look at a dot shown at different locations on the display screen. Calibrations were accepted with mean error below 0.5° for all children. A small one-point-calibration was then used before the onset of each trial to correct for drifts. At the beginning of each trial, a fixation cross (1°) was shown at the centre of the black screen for a variable duration of 500–900 ms, and participants were asked to look at the middle of this cross. The fixation cross was replaced by the target display, which was presented for 1200 ms, and during which participants were instructed to look to the central black square inside the oval shape as quickly and accurately as possible, until it disappeared. They were also instructed to ignore any other stimuli that might be presented with the targets. Finally, a blank screen was presented for 500 ms (see Figure 2 for a schematic of the trial sequence).

Eye movement measures

Errors (first saccades made towards the distractors with an amplitude greater than 2.2°) and Saccade Latencies (first saccades initiated to the target with a saccade amplitude greater than 2.2°) were adopted to investigate reflexive and voluntary orienting. These two measures have been typically adopted in the RDP studies (Pavlou et al., 2016; Richards et al., 2012; Zhang et al., 2020, 2021), to investigate how stimuli (as distractors) affect the involuntary (errors) and voluntary (latencies) orienting systems. Therefore, these two measures allow us to investigate both types of attentional processing in the same experiment.

Data exclusion criteria

Trials were excluded when (1) a blink during the first saccade was made (2.24%), (2) the start position of the first saccade exceeded 1° (the selection of 1° criterion was based on the size of the central fixational cross, to ensure participants have similar saccade initiating positions prior to the target screen) from the centre of the screen (5.26%), (3) saccade amplitude of the first eye movement was less than 2.2° (because this meant that participants were still fixating within the distractor area) (3.17%), (4) an anticipatory saccade (first saccade with latency shorter than 80 ms, Wenban-Smith & Findlay, 1991) was made (0.51%), to make sure saccades were stimulus driven, (5) saccade amplitude of the first eye movement made towards the opposite direction to the target in single target and central distractor

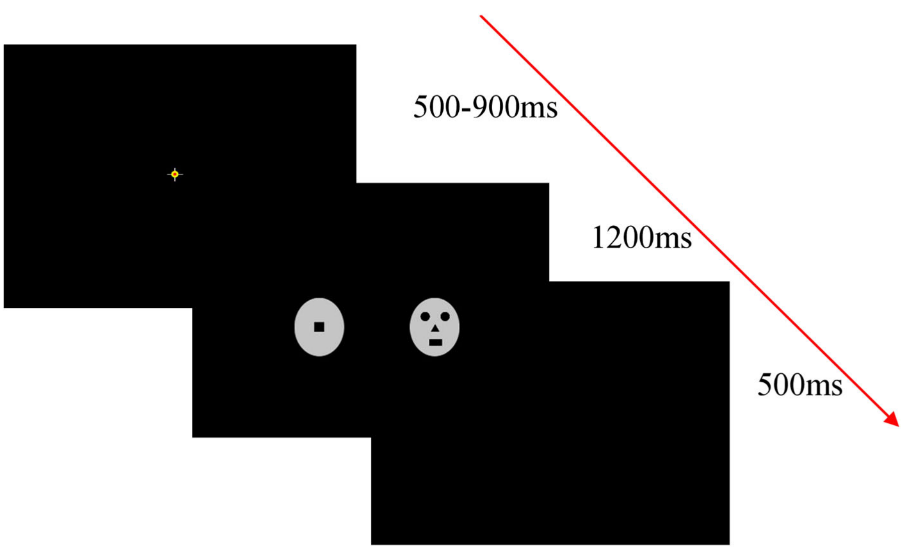

Figure 2. A schematic example of a distractor trial sequence in the RDP displaying the face-like distractor and the target presented in parafovea.

conditions was greater than 2.2° (0.04%), and (6) saccade latencies were greater or smaller than 3 standard deviations away from the mean value of each individual participant mean (0.60%). A total of 7086 trials were included in the LMM analyses. Furthermore, there was no group difference in the total proportions of removed trials, $t = 1.32$, $p > 0.05$ (ASC: $M = 0.14$, $SD = 0.08$; TD: $M = 0.10$, $SD = 0.07$).

Data analysis

Data were analysed using the Linear mixed models (LMMs, lme4 package, Version 1.1-17) in R environment (version 4.0.2, R Development Core 2014). By fitting each individual's data into the model, LMMs outperform Anova analyses in specifying random factors such as participants and items, and do well in avoiding loss of statistical power caused by missing data or unbalanced designs (e.g. Kliegl et al., 2011). In the current LMMs analyses, group, distractor type and distractor position were included as fixed factors. Random intercept and random slope for the fixed effects over participants were considered at maximum, as long as the model could converge. Simple models were conducted when the full model failed to converge. Specifically, in LMM models, the random effect for participants was trimmed by starting with the random-effect correlations, and then the random slopes, until it converged successfully, for all the measures. Saccade latency was log-transformed before the final analyses to reduce the impact of data skewness. Differences for paired-contrasts for each fixed factor were indicated by *t*-value for saccade latency and *z*-value for error rates by using logit-link functions. The 95% confidence interval of *z*-value or *t*-value for each fixed effect was also presented in the statistical result tables (Tables 2, 5 and 6) for both experiments.

Results

Directional errors

Directional error rates reflect the ratio between error trials and total valid trials which included error trials and correct trials in the parafoveal and peripheral distractor positions. More errors were shown in the face-like distractor condition ($M = 0.50$, $SD = 0.50$) than the non-face-like distractor condition ($M = 0.43$, $SD = 0.50$) for all participants, $b = -0.31$, $SE = 0.07$, $z = -4.23$, $p < 0.001$ (See Figure 3 for details). There were no significant differences for group or distractor position, and no interactions, $|z|s < 1.4$, $ps > 0.05$. This finding suggests that reflexive orienting to facial configuration is similar in both groups, and the finding contrasts with our prediction of a greater effect in the TD group. Detailed statistical results for the two measures in Experiment 1 are shown in Table 2.

Saccade latency

Basic distractor effects are defined as the difference between the latencies for distractor trials and the latencies for single target trials. It would be expected that a basic distractor effect of longer latencies for distractor trials compared to single target trials would be found for all distractor type conditions. Significant basic distractor effects were found for both groups in each distractor type condition, in which all participants took longer to execute an eye movement to the target in distractor trial conditions, compared with the single target condition, $|t|s > 15$, $ps < 0.001$, and no group difference was observed for this basic distractor effect, $|t|s < 1.8$, $ps > 0.05$. This baseline finding validates the use of the RDP paradigm for examining attentional processing for face-like distractors.

Following the calculation of the basic distractor effects, single target latencies were removed, and the remote distractor effects for distractor trials were analysed using LMMs, whereby group, distractor type and distractor position were taken as the fixed factors. As would be predicted for the RDP paradigm, the longest saccade latencies were observed for the central distractor condition ($M = 363$ ms, $SD = 113$ ms), followed by the parafoveal condition ($M = 283$ ms, $SD = 99$ ms) and the peripheral condition ($M = 257$ ms, $SD = 85$ ms), $|t|s > 3.9$, $ps < 0.001$. However, group effect, distractor type effect and all interactions were non-significant, $|t|s < 1.7$, $ps > 0.05$ (See Table 3 for descriptive statistic details). This finding shows that both face-like and non-face-like distractor types produced the same effects, for both groups,[1] and this also contrasts

[1]The Bayesian analyses were conducted using *BayesFactor* package (0.9.12-4.3; Rouder et al., 2012) in R environment (version 4.0.2, R Development Core 2014), on the null interactions (*group × distractor type*, *group × distractor position*, *distractor type × distractor position*, *and group × distractor type× distractor position*) on saccade latency. By taking the default value of 10,000 for iterations (or Monte Carlo simulations) and 0.5 for rscaleFixed (a medium value adopted to select the prior scale for standardized, reduced fixed effects) in Bayesian analyses, the ratio of the target model without specific interaction effect (BF01) to the full model (BF02) was calculated for Experiment1. The BF ratios (BF01/BF02) for the

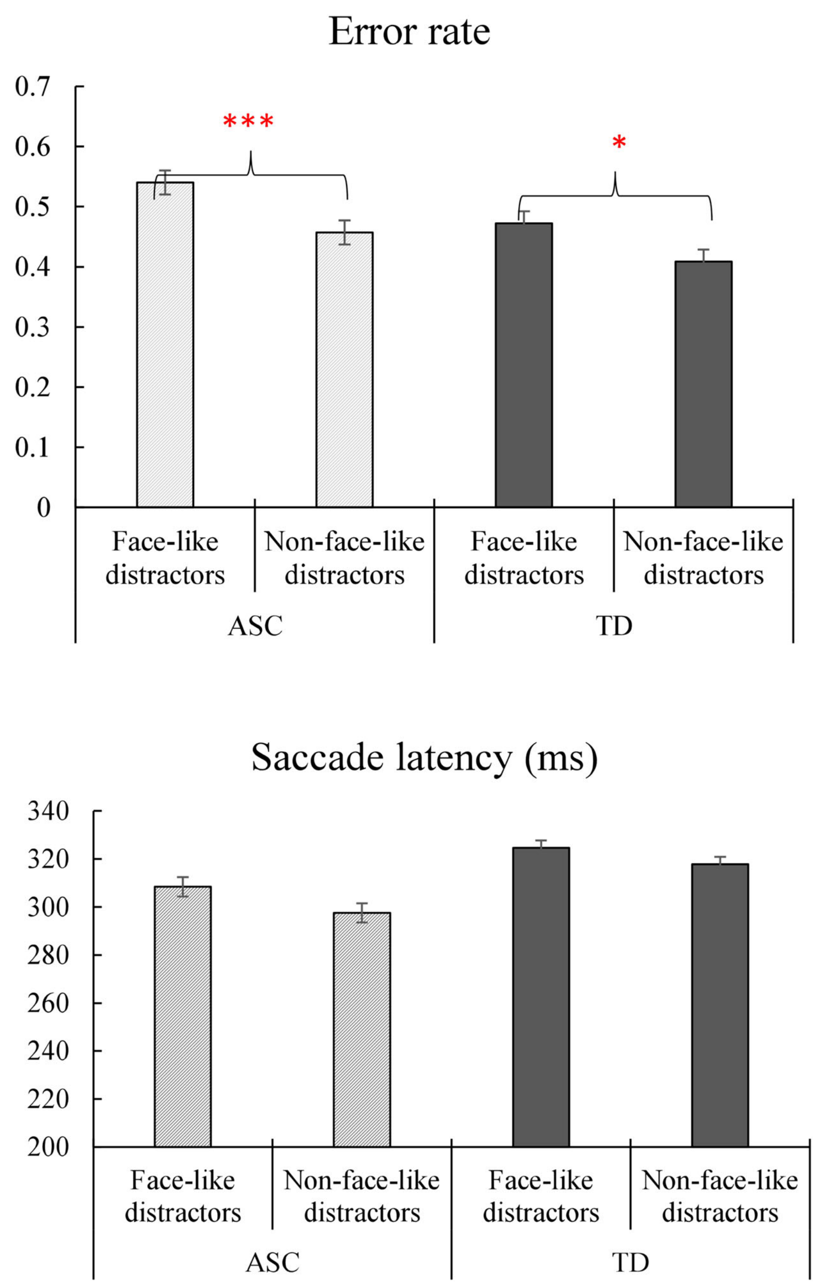

Figure 3. Distractor type effect results for both the ASC and TD groups on the error rate (top) and saccade latency (bottom) in Experiment 1.

with our earlier prediction of an expected greater effect for the TD group.

The error rate data revealed that both groups showed a preference for reflexively orienting to facial-like stimuli compared to non-facial-like stimuli. This finding demonstrates an ability in ASC to extract the facial configuration in a reflexive (or intuitive) way when these stimuli are presented outside of the fovea, and, although this contradicts the evidence for local processing in ASC the finding is in line with a previous report of a relative intact ability to process the configural structure of schematic faces at the reflexive level in ASC (Akechi et al., 2015; Johnson, 2014; Shah et al., 2013).

However, all participants failed to show a face configuration effect on latencies and it is not immediately clear as to why this happened. One explanation for this could relate to the stimuli,

null interactions on saccade latency were all greater than 17 (15–120), favouring the null hypothesis at a relative strong confidence level (Wagenmakers et al., 2018).

Table 2. Statistical details of LMM analyess in Experiment 1.

Fixed effects	b	95%CI	SE	t/z	Cohen's d
The basic distractor effects on saccade latency for facial-like stimuli (a)					
Group: ASC vs. TD	0.06	[−0.02, 0.15]	0.04	1.39	
Distractor presence: DT vs. ST	−0.43	[−0.48, −0.38]	0.02	−17.94 ***	−1.25
Group ×Distractor presence	0.01	[−0.09, 0.10]	0.05	0.11	
The basic distractor effects on saccade latency for non-facial-like stimuli (b)					
Group: ASS vs. TD	0.09	[−0.01, 0.19]	0.05	1.77.	
Distractor presence: DT vs. ST	−0.39	[−0.45, −0.34]	0.03	−15.36***	−1.12
Group ×Distractor presence	0.01	[−0.09, 0.12]	0.05	0.28	
The remote distractor effects on saccade latency (c)					
Group: ASC vs. TD	0.09	[−0.02, 0.19]	0.05	1.66	
Distractor position: C vs. NR	0.29	[0.22, 0.35]	0.03	8.72***	0.75
Distractor position: C vs. FAR	0.38	[0.32, 0.44]	0.03	12.43***	1.06
Distractor position: NR vs. FAR	0.09	[0.04, 0.13]	0.02	3.92***	0.28
Distractor type: FL vs. NFL	−0.01	[−0.04, 0.02]	0.02	−0.58	
Group × C vs. NR	−0.06	[−0.19, 0.07]	0.07	−0.93	
Group × C vs. FAR	−0.08	[−0.20, 0.04]	0.06	−1.25	
Group ×NR vs. FAR	−0.02	[−0.10, 0.07]	0.05	−0.33	
Group × FL vs. NFL	0.01	[−0.06, 0.08]	0.03	0.28	
C vs. NR × FL vs. NFL	−0.05	[−0.11, 0.02]	0.03	−1.41	
C vs. FAR × FL vs. NFL	−0.02	[−0.07, 0.04]	0.03	−0.57	
NR vs. FAR × FL vs. NFL	0.03	[−0.02, 0.08]	0.03	1.12	
Group × C vs. NR × FL vs. NFL	0.04	[−0.09, 0.16]	0.06	0.56	
Group × C vs. FAR × FL vs. NFL	0.01	[−0.11, 0.13]	0.06	0.18	
Group × NR vs. FAR × FL vs. NFL	−0.03	[−0.13, 0.07]	0.05	−0.50	
The remote distractor effects on saccade error rate (d)					
Group: ASC vs. TD	−0.25	[−0.61, 0.10]	0.18	−1.40	
Distractor position: NR vs. FAR	−0.03	[−0.19, 0.13]	0.08	−0.37	
Distractor type FL vs. NFL	−0.31	[−0.45, −0.17]	0.07	−4.23***	−0.16
Group × NR vs. FAR	−0.02	[−0.34, 0.29]	0.16	−0.13	
Group × FL vs. NFL	0.10	[−0.19, 0.38]	0.15	0.66	
NR vs. FAR × FL vs. NFL	0.02	[−0.26, 0.29]	0.14	0.12	
Group × NR vs. FAR × FL vs. NFL	−0.04	[−0.59, 0.50]	0.28	−0.15	

Note: ***p < 0.001.

Table 3. The means and standard deviations of eye movement measures for different distractor positions, types and groups in Experiment 1.

		ASC		TD	
		SL (ms)	ER	SL (ms)	ER
FLD	C	362 (117)		372 (110)	
	NR	271 (99)	0.53 (0.50)	294 (90)	0.47 (0.50)
	FAR	246 (91)	0.55 (0.50)	272 (82)	0.48 (0.50)
	ST	194 (66)		208 (73)	
NFLD	C	348 (118)		366 (105)	
	NR	271 (113)	0.46 (0.50)	292 (93)	0.40 (.49)
	FAR	239 (81)	0.46 (0.50)	267 (83)	0.41 (.49)
	ST	192 (55)		216 (80)	

Notes: In Experiment 1, C is for central distractor condition, NR for parafoveal and FAR for peripheral distractor conditions. SL is the saccade latency; ER is the error rate; FLD refers to the face-like distractors and NFLD to the non-face-like distractors.

which were schematically presented and thus clearly different from real faces. At the voluntary attentional level the stimuli in the current experiment might be more easily ignored than real faces, which have been shown to produce a robust delay in responding to peripheral targets in a TD group (Bindemann et al., 2005). Moreover, individuals with ASC tend to show preserved processing for cartoon faces but not for real faces (e.g. Rosset et al., 2008; van der Geest et al., 2002). To control for this possibility, in the next experiment, we employed real neutral faces as distractors and also adopted a new measure (disengagement failure rates) which allowed us to measure the number of trials where participants made more than one fixation within the distractor when this was presented at the central location, prior to looking to the target (Zhang et al., 2021). Thus, the disengagement failure rate can provide a further measure of the influence of face distractors on voluntary attentional processing (in addition to saccade latency), whereby a higher failure rate reflects a greater "holding" of attention of participants.

In Experiment 2 we employed real neutral faces and scrambled faces, (in line with Experiment 1 conditions), and we also included a blurred neutral face as a control condition (see materials section for an explanation of how these were created). Another possible reason for the lack of effects in the latencies in Experiment 1 could relate to both types of distractor in that experiment containing the same information (shape components) but in different configural arrangements. In Experiment 2 the preserved neutral face distractors and the scrambled face distractors also contain the same information, but in different configurations, and therefore may, potentially, produce similar effects to those observed in Experiment 1. We therefore included blurred faces as a control condition in Experiment 2. If it is the schematic nature of the distractors that is driving the effects in Experiment 1, then we predict that preserved real face distractors should result in more interference for the TD group compared to the scrambled and the blurred face distractors. If the TD group engages in a global processing strategy this effect should be observed at both the reflexive (errors) and voluntary (latencies or disengagement failure rates) attentional processing levels. Moreover, if the ASC group does not engage in global processing of real faces these effects might be expected to be reduced or absent in the ASC group.

Experiment 2

Methods

Participants

Fifteen ASC children (3 female, 4.5–7 years old) and 18 typical children (4 female, 4.5–6.5 years old) took part in this experiment. Two boys in the ASC group failed to complete the full test procedures and for that reason they were excluded from the final analysis. No neurodevelopmental deficit history was reported for the TD children. Children in both groups had normal or corrected-to-normal vision. ASC diagnoses and confirmation procedures were similar to those reported in Experiment 1. AQ scores were higher in the ASC children, $t = 5.00$, $p < 0.001$. Both groups were matched on VIQ, PIQ and FSIQ, $ts < 1.5$, $ps > 0.05$. No differences were found in chronological ages between the ASC and TD groups, $t = 0.74$, $p > 0.05$ (see Table 4 for details).

Materials

The same ellipse target (4.35° X 5.42°) from Experiment 1was utilised for Experiment 2. Neutral, Scrambled and Blurred face distractors were the same size as the target. Twelve Chinese neutral face models (6 males and 6 females) were selected from the Chinese Affective Face Picture System (Gong et al., 2011). Scrambled faces were produced by systematically disorganising the facial configuration in the twelve neutral faces. Blurred faces were created by applying the Gaussian Blur tool in Adobe Photoshop to one female face model and then placing two crossed black lines over the blurred image. Specifically, the blurring process for real faces was aimed to retain the physical features (e.g. luminance and contrast) of the faces in the baseline condition. The two crossed black lines were placed over the blurred images to further reduce the face nature of this distractor type. Social information conveyed by blurred faces should be reduced compared to neutral and scrambled faces, and thus should be predicted to produce the least interference for attentional orienting at both the reflexive and voluntary levels. Target and distractors were greyscale and in the same oval form (See Figure 1 for stimuli examples). Consistent with Experiment 1, targets were displayed either in isolation, or with central, parafoveal (5°) or peripheral (10°) distractors simultaneously. There were 144 trials for each distractor type block and each block included 48 single target trials and 96 distractor trials. A total of 432 trials were presented to each participant in Experiment 2. A similar method was utilised to estimate the power for Experiment 2. The power values ranged from 0.78 to 0.97 for distractor type effect, distractor position effect and all interactions, based on a participant number of 13 per group and an average effect size of $d = 0.45$. The results suggest an acceptable power level for Experiment 2 overall.

Table 4. Demographic data (mean ± SD) of the ASC and TD groups on age, IQ and AQ scores in Experiment 2.

	ASC ($n = 13$)	TD ($n = 18$)	t	p
Age (months)	70.00 (10.14)	67.83 (6.13)	0.74	0.47
VIQ	107.62 (15.44)	112.67 (8.44)	−1.17	0.25
PIQ	109.38 (12.19)	107.17 (12.57)	0.49	0.63
FSIQ	110.62 (11.66)	108.78 (7.08)	0.55	0.59
AQ	82.54 (11.09)	60.83 (12.49)	5.00	< **0.001**

Eye movement measures

Three eye movement measures were adopted in Experiment 2. Saccadic errors and saccade latency were the same as in Experiment 1. A third measure, failure to disengage (from the central distractors in the first eye movement with saccade amplitude less than 2.2°) was also adopted to further investigate voluntary control. Disengagement failure rate was defined as the proportion of trials where participants did not look to the target with their first saccade, but instead remained looking within the central distractors.

Apparatus and procedures

The same eye-tracking system (sampling 500 times per second) and display monitor as those used in

Experiment 1 were adopted in Experiment 2 and the procedures in Experiment 2 also replicated those in Experiment 1. The sampling rate of eye movements in Experiment 1 was 1000 Hz, and it was 500 Hz in Experiment 2. This different sampling rate occurred because in each experiment a different version of the Portable Duo tracker had to be used to collect the data. The two different sampling rates will not have affected the results in any way.

Data exclusion criteria

The same rationale for exclusion criteria in Experiment 1 was adopted for Experiment 2. Data were removed when (1) blinks were made (3.68%), (2) saccade start position exceeded 1° from the centre of the screen (6.12%), (3) anticipatory saccades occurred (1.86%), (4) saccades were triggered towards the opposite direction of the target with amplitude greater than 2.2° in central distractor and single target conditions (0.20%), (5) saccade amplitudes in parafoveal, peripheral or single target condition were less than 2.2° (0.44%), and (6) saccade latencies were three standard deviations higher or lower than the mean value for each participant (0.63%). No difference was found for the total number of removed trials between the ASC ($M = 0.14$, $SD = 0.05$) and TD ($M = 0.12$, $SD = 0.07$) groups, $t = 0.70$, $p > 0.05$. A total of 11609 trials were included in the final LMM analyses.

Results

Directional errors

Significant distractor type effects were found in all children, whereby both the neutral ($M = 0.62$, $SD = 0.49$) and the scrambled ($M = 0.60$, $SD = 0.49$) face distractors triggered more erroneous saccades directed towards the distractor, compared to the blurred face ($M = 0.42$, $SD = 0.49$) distractors, $|z|\text{s} > 5$, $ps < 0.001$. However, other fixed factor effects and interactions did not reach significance, $|z|\text{s} < 1.7$, $ps > 0.05$. In line with the findings from Experiment 1, the findings for Experiment 2 provide evidence to suggest that reflexive orienting to face-like distractors is similar for both groups. Details of the statistical results for all measures in Experiment 2 are presented in Tables 5 and 6.

Disengagement failure rate

For disengagement failure rates, effects of distractor type were found, whereby the disengagement failure rates were higher in neutral face ($M = 0.12$, $SD = 0.33$) and scrambled face conditions ($M = 0.13$, $SD = 0.34$), compared with the blurred face condition ($M = 0.03$, $SD = 0.17$), $|z|\text{s} > 4$, $ps < 0.001$. However, there was no significant group effect or interaction, $|z|\text{s} < 1.6$, $ps > 0.05$. This result for the neutral preserved face and scrambled face distractors is in line with the error data and shows that the rate of failure to disengage (with the first saccade) from the centrally presented distractors is equivalent for both preserved and scrambled faces, for both groups.

Saccade latency

As in Experiment 1, in Experiment 2 basic distractor effects were shown to be significant in all participants for all distractor types, $|t|\text{s} > 16$, $ps < 0.001$, whereby all participants produced longer latencies for distractor trials compared to single target trials in each of the distractor type conditions, and there was no group difference in either distractor or single target trials in each distractor type condition, $|t|\text{s} < 0.7$, $ps > 0.05$. The expected remote distractor effects were found in all participants, showing longest saccade latencies in the central distractor condition ($M = 317$ ms, $SD = 125$ ms), followed by the parafoveal condition ($M = 251$ ms, $SD = 84$ ms) and the peripheral condition ($M = 230$ ms, $SD = 76$ ms), $|t|\text{s} > 3$, $ps < 0.01$. There was also a significant distractor type effect, whereby participants latencies were longer for scrambled faces ($M = 300$ ms, $SD = 112$ ms), compared to blurred faces ($M = 276$ ms, $SD = 117$ ms), $b = -0.05$, $SE = 0.02$, $t = -2.80$, $p = 0.008$. Differences between neutral face ($M = 298$ ms, $SD = 121$ ms) and blurred face conditions also reached significance, $b = -0.05$, $SE = 0.02$, $t = -2.03$, $p = 0.050$. However, no difference was found between the ASC ($M = 300$ ms, $SD = 128$ ms) and TD groups ($M = 286$ ms, $SD = 109$ ms), $b = -0.08$, $SE = 0.06$, $t = -1.16$, $p > 0.05$. These main effects show, in comparison to blurred faces, longer latencies occurred for both preserved and scrambled faces, for both groups.

Significant interactions between distractor type by position, $|t|\text{s} > 2.8$, $ps < 0.01$, showed that differences between scrambled and blurred faces were more robust in the central distractor condition, $b = -0.12$, $SE = 0.03$, $t = -4.56$, $p < 0.001$, relative to parafoveal and peripheral conditions($|t|\text{s} < 1.6$, $ps > 0.05$), and similarly, distractor differences between neutral and blurred faces were greater in the central distractor condition, $b = -0.09$, $SE = 0.03$, $t = -3.38$, $p = 0.002$, compared to peripheral condition, $b = 0.00$, $SE = 0.03$, $t = 0.01$, $p > 0.05$.

Table 5. Statistical details of LMM analyses on saccade latency in Experiment 2.

Fixed effects	b	95%CI	SE	t	Cohen's d
The basic distractor effects for neutral face distractors					
Group: ASC vs. TD	−0.03	[−0.14, 0.07]	0.05	0.57	
Distractor presence: DT vs. ST	−0.50	[−0.56, −0.45]	0.03	16.91***	1.41
Group ×Distractor presence	0.10	[−0.02, 0.22]	0.06	1.69	
The basic distractor effects for scrambled face distractors					
Group: ASC vs. TD	0.02	[−0.10, 0.15]	0.06	0.3	
Distractor presence: DT vs. ST	−0.50	[−0.56, −0.44]	0.03	−16.99***	−1.38
Group ×Distractor presence	0.04	[−0.08, 0.16]	0.06	0.67	
The basic distractor effects for blurred face distractors					
Group: ASC vs. TD	−0.04	[−0.12, 0.08]	0.03	−0.62	
Distractor presence: DT vs. ST	−0.42	[−0.47, −0.37]	0.03	−16.32***	−1.17
Group ×Distractor presence	0.06	[−0.04, 0.16]	0.05	1.09	
The remote distractor effects					
Group: ASC vs. TD	−0.08	[−0.20, 0.05]	0.06	−1.16	
Distractor position: C vs. NR	0.24	[0.17, 0.30]	0.03	6.93***	0.63
Distractor position: C vs. FAR	−0.32	[−0.38, −0.25]	0.03	−9.10***	−0.85
Distractor position: NR vs. FAR	0.08	[0.03, 0.13]	0.02	3.17**	0.26
Distractor type: NF vs. SF	0.01	[−0.03, 0.05]	0.02	0.43	
Distractor type: SF vs. BF	−0.05	[−0.09, −0.02]	0.02	−2.80**	−0.21
Distractor type: NF vs. BF	−0.05	[−0.09, −0.00]	0.02	−2.03*	−0.18
Group × C vs. NR	−0.09	[−0.05, 0.22]	0.07	−1.27	
Group × C vs. FAR	−0.05	[−0.19, 0.08]	0.07	−0.76	
Group × NR vs. FAR	0.03	[−0.13, 0.06]	0.05	0.68	
Group × NF vs. SF	0.11	[0.04, 0.19]	0.04	2.92**	0.52
Group × SF vs. BF	−0.08	[−0.16, −0.01]	0.04	−2.10*	−0.38
Group × NF vs. BF	0.03	[−0.06, 0.12]	0.05	0.64	
C vs NR × NF vs. SF	0.02	[−0.03, 0.08]	0.03	0.86	
C vs NR × SF vs. BF	0.07	[0.02, 0.12]	0.03	2.81**	0.50
C vs NR × NF vs. BF	0.05	[−0.10, 0.00]	0.03	1.86	
C vs FAR × NF vs. SF	0.00	[−0.05, 0.06]	0.03	0.12	
C vs FAR × SF vs. BF	0.09	[0.04, 0.14]	0.03	3.38***	0.61
C vs FAR × NF vs. BF	0.09	[0.04, 0.14]	0.03	3.49***	0.63
NR vs FAR × NF vs. SF	0.03	[−0.04, 0.09]	0.03	−0.77	
NR vs FAR × SF vs. BF	0.02	[−0.05, 0.08]	0.03	0.49	
NR vs FAR × NF vs. BF	0.04	[−0.02, 0.11]	0.03	1.31	
Group × C vs. NR × NF vs. SF	−0.01	[−0.12, 0.10]	0.05	−0.16	
Group × C vs. NR × SF vs. BF	−0.03	[−0.13, 0.07]	0.05	−0.55	
Group × C vs. NR × NF vs. BF	0.04	[−0.06, 0.14]	0.05	0.71	
Group × C vs. FAR × NF vs. SF	−0.06	[−0.17, 0.05]	0.06	−1.08	
Group × C vs. FAR × SF vs. BF	0.01	[−0.09, 0.11]	0.05	0.24	
Group × C vs. FAR × NF vs. BF	−0.05	[−0.15, 0.05]	0.05	−0.91	
Group × NR vs. FAR × NF vs. SF	−0.07	[−0.20, 0.07]	0.07	−0.98	
Group × NR vs. FAR × SF vs. BF	−0.02	[−0.11, 0.14]	0.07	−0.25	
Group × NRvs. FAR × NF vs. BF	−0.08	[−0.21, 0.04]	0.06	−1.30	

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$.

However, a significant interaction of group by distractor type, $|t|\text{s} > 2$, $ps < 0.05$ and further analyses revealed that TD children produced longer saccade latencies in the scrambled face condition, compared to the preserved neutral face condition ($b = 0.06$, $SE = 0.02$, $t = 2.77$, $p = 0.012$) and the blurred face condition ($b = -0.13$, $SE = 0.02$, $t = -5.66$, $p < 0.001$) and this finding was absent in the ASC group $|t|\text{s} < 2.1$, $ps > 0.05$. (See Table 7 and Figure 4 for detailed results). No other interactions were significant for this measure.[2]

It is possible that the unpredicted greater effects for scrambled faces in the TD group could mask any group differences from being observed between the neutral and blurred face distractor conditions. To test for this possibility, we excluded the scrambled face trials from the LMM analysis, and the results showed the expected distractor type effects of greater interference from neutral faces compared to blurred faces, in both groups on all three eye movement measures (this effect on saccade latency was robustly observed in the central condition), $|t|\text{s} > 3$, $ps \leq 0.001$. Importantly, an interaction for disengagement failure rate, $b = 0.84$, $SE = 0.39$, $t = 2.16$, $p = 0.03$, showed that

[2]The Bayesian analyses were conducted using similar methods to those adopted in Experiment 1 for the null interactions (*group* × *distractor position and group* × *distractor type*× *distractor position*) in Experiment 2. The BF ratio (BF01/BF02) was around 30 for the null interactions of *group* × *distractor position*, and about 50 for the null interactions of *group* ×*distractor type* × *distractor position*. The results supported the null hypothesis at a strong confidence level.

Table 6. Statistical details of LMM analyses on saccade error rate and disengagement failure rate (DFR) in Experiment 2.

Fixed effects	*b*	*95%CI*	*SE*	*z*	*Cohen's d*
Distractor effects on saccade error rate					
Group: ASC vs. TD	−0.02	[−0.43, 0.38]	0.21	−0.11	
Distractor position: NR vs. FAR	0.06	[−0.07, 0.20]	0.07	0.90	
Distractor type: NF vs. SF	−0.05	[−0.25, 0.15]	0.10	−0.48	
Distractor type: SF vs. BF	−0.81	[−1.09, −0.53]	0.14	−5.68***	−0.36
Distractor type: NF vs. BF	−0.86	[−1.14, −0.58]	0.14	−6.04***	−0.40
Group × NR vs. FAR	−0.22	[−0.49, 0.05]	0.14	−1.57	
Group × NF vs. SF	−0.33	[−0.74, 0.07]	0.21	−1.61	
Group × SF vs. BF	0.38	[−0.18, 0.94]	0.29	1.32	
Group × NF vs. BF	0.05	[−0.51, 0.60]	0.29	0.16	
NR vs FAR × NF vs. SF	0.04	[−0.29, 0.38]	0.17	0.26	
NR vs FAR × SF vs. BF	0.06	[−0.27, 0.39]	0.17	0.35	
NR vs FAR × NF vs. BF	0.10	[−0.23, 0.43]	0.17	0.61	
Group × NR vs. FAR × NFvs. SF	−0.39	[−1.06, 0.29]	0.34	−1.13	
Group × NR vs. FAR × SF vs. BF	−0.02	[−0.68, 0.64]	0.34	−0.07	
Group × NRvs. FAR × NF vs. BF	−0.41	[−1.07, 0.25]	0.33	−1.22	
Distractor effects on DFR					
Group	−0.43	[−1.25, 0.40]	0.42	−1.02	
NF vs. SF	0.13	[−0.31, 0.57]	0.23	0.59	
SF vs. BF	1.49	[0.88, 2.09]	0.31	4.83***	0.38
NF vs. BF	−1.35	[−1.94, −0.76]	0.30	−4.48***	−0.35
Group × NF vs. SF	0.23	[−0.57, 1.03]	0.41	0.57	
Group × SF vs. BF	0.52	[−0.50, 1.53]	0.52	1.00	
Group × NF vs. BF	0.75	[−0.23, 1.73]	0.50	1.51	

Notes: The group by distractor type interaction was significant when excluding the SF trials from the LMM analyses, $b = 0.84$, $SE = 0.39$, $t = 2.16$, $p = 0.03$, $d = 0.79$, compared to the findings shown above by including the three distractor types in the LMM analyses. ***$p < 0.001$.

Table 7. The means and standard deviations of eye movement measures for different distractor positions, types and groups in Experiment 2.

		ASC			TD		
		SL (ms)	ER	DFR	SL (ms)	ER	DFR
NFD	C	339 (144)		0.18 (0.38)	315 (114)		0.08 (0.28)
	NR	282 (99)	0.61 (0.49)		238 (77)	0.62 (0.49)	
	FAR	243 (80)	0.60 (0.49)		222 (77)	0.63 (0.48)	
	ST	171 (43)			176 (51)		
SFD	C	318 (121)		0.18 (0.38)	335 (109)		0.10 (0.30)
	NR	257 (84)	0.60 (0.49)		250 (76)	0.59 (0.49)	
	FAR	240 (105)	0.64 (0.48)		229 (66)	0.56 (0.50)	
	ST	174 (59)			182 (57)		
BFD	C	314 (149)		0.03 (0.18)	293 (116)		0.03 (0.17)
	NR	263 (91)	0.37 (0.48)		232 (71)	0.44 (.50)	
	FAR	239 (72)	0.44 (0.50)		220 (65)	0.42 (.49)	
	ST	177 (54)			173 (46)		

Notes: In Experiment 2, DFR is the disengagement failure rate for the first saccade. NFD, SFD, and BFD refer to the neutral face distractors, scrambled face distractors and blurred face distractors respectively.

the distractor type effect was larger in ASC ($b = -2.09$, $SE = 0.29$, $t = -7.10$, $p < 0.001$), relative to the TD group ($b = -1.23$, $SE = 0.26$, $t = -4.75$, $p < 0.001$, See Figure 5 for details). In line with our previous findings (Zhang et al., 2020, 2021), this result suggests that there are increased disengagement difficulties from central neutral faces in the ASC compared to the TD group.

General discussion

The aim of the current study was to investigate the influence of face and non-face distractors on reflexive and voluntary attentional processes in children with and without ASC. We found evidence of reflexive orienting towards face and face-like distractors coupled with increased voluntary disengagement difficulties from neutral preserved face distractors, when these were presented centrally, in ASC children. The TD children showed a scrambled face bias at the voluntary attentional level, and this bias was absent in the ASC group.

Both groups made high proportions of error rates in all distractor conditions. The error rates reported for the blurred face (42%) and non-face-like (43%) distractors in the two experiments presented in the current paper, were similar with the result from a previous RDP study using simple shape

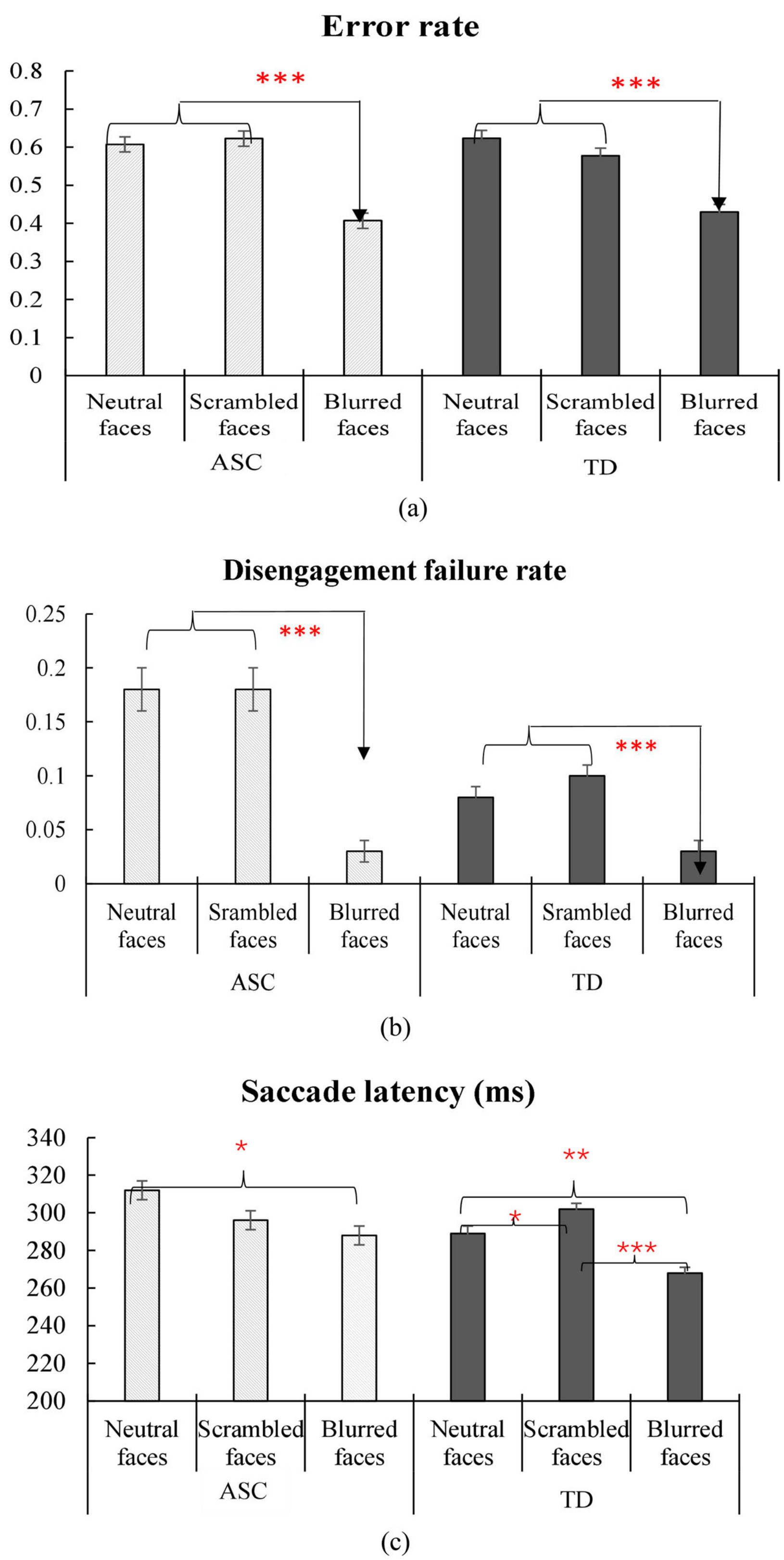

Figure 4. Distractor type (with scrambled faces) effect results for both the ASC and TD groups on the error rate (a), disengagement failure rate (b) and saccade latency (c) in Experiment 2.

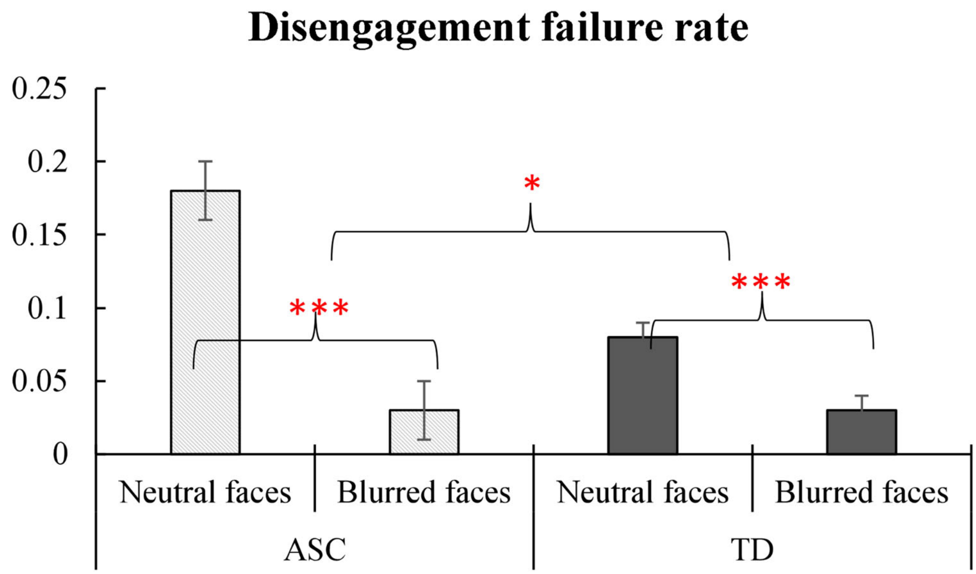

Figure 5. Distractor type (without scrambled faces) effect results for both the ASC and TD groups on disengagement failure rate in Experiment 2.

distractors (43%, Zhang et al., 2020). These consistent reports of high error rates in both groups of children are shown to associate with under-developed voluntary control in young children per se (Luna et al., 2008; Zhang et al., 2020).

However, increased error rates for the face-like distractors, and for real face distractors in the current paper indicate that children with and without ASC execute involuntary attention to facial stimuli equivalently, regardless as to whether the facial stimuli are typical or scrambled. This scrambled face effect for errors could result from the presence of all facial features, albeit in a scrambled pattern, in these distractors. Specifically, the scrambled facial information presented outside of the fovea still has the potential to capture children's attention involuntarily. Furthermore, the adoption of face-like and non-face-like distractors in Experiment 1, well-matched on low-level visual properties, confirms a prioritised role for facial configuration in capturing reflexive orienting in all participants. These findings support the view that the basic function of directing rapid and reflexive attention to faces is preserved in young children with ASC. Additionally, the results point to an advantage of pre-attentive processing of facial stimuli in ASC, highlighting a prominent status for faces in the "salience map" of visual attention (Itti & Koch, 2000; Yu et al., 2017) in this group. Compared to the prevailing social orientation hypothesis related to ASC (e.g. Dawson et al., 2012), which proposes that reduced or slowed attention towards social items in ASC is rooted in social and cognitive underdevelopment in ASC, the current findings suggest that atypical social communication observed in ASC is not related to face orientation deficits, at least not at the reflexive orienting level.

One unexpected, but potentially important group difference reported in the current study is the scrambled face distractor bias found in the TD group. Although we predicted reduced distractor effects for scrambled faces compared to neutral faces in Experiment 2, the TD group took longer to disengage from scrambled faces compared to neutral and blurred faces. According to the global face processing theory, we suggest that this finding could be related to how this type of stimulus fits with the existence of a typical face prototype in that group. Disorganised scrambled facial features are strange and novel, and they violate the normal configuration of a face, and as such they could hold attention for longer if the default is to process faces at a global level. In line with this idea, event-related potential (ERP) studies find that humans make more errors recognising scrambled faces (Donnelly & Davidoff, 1999) and need longer to process them neurologically (George et al., 1996) than they do for normal or typical faces. The absence of the scrambled face effect in the ASC group could reflect an inefficiency in global processing of faces in that group. In other words, children with ASC in the current study appear to prefer a local- or featured-based processing strategy to process neutral and scrambled faces, and this contrasts with the holistic processing style adopted in the TD group. Therefore, consistent with previous studies that report a preferential local processing of faces in facial identity or emotion recognition tasks (Falck-Ytter, 2008), the current study adds new evidence to this field by revealing evidence to support this strategy in attentional disengagement from real faces at the voluntary level in ASC.

A further group difference that has been revealed from the current study is the increased neutral face distractor effect on disengagement failure rates in ASC. This finding is consistent with the face-related "sticky attention" findings observed in individuals with ASC in early life (Elsabbagh et al., 2013; Hendry et al., 2018), and provides new evidence of a delayed disengagement from fixated neutral faces in preschool children with ASC at the voluntary level. This finding may also be accounted for by a preference for a local-based processing style in the ASC group, since they made more fixations within the central faces, before successful disengagement, for neutral faces compared to blurred faces. Moreover, this cognitive difference demonstrates less efficient voluntary attentional shifting from fixated real facial information in ASC, and this difference could cause a delay in the detection of, and hence the utilisation of, new important social information that is presented away from the current focus of attention. As such, this disengagement atypicality could be a factor underpinning atypical development of higher-level social perception and cognition in ASC.

Conclusion

In sum, the current findings indicate a bias in reflexive orienting to face stimuli, coupled with increased voluntary disengagement from centrally presented neutral face distractors in ASC. However, children with ASC fail to exhibit the special influence of scrambled face distractors that is observed for TD children at the voluntary level. These cognitive processing differences suggest that individuals with ASC may be less effective at adopting a global processing strategy when visually attending to real faces at the voluntary attentional level. This atypicality in ASC has potential to lead to inefficient or delayed processing of social information. Together these effects have potential to contribute to impairments in typical development of social cognition, ultimately leading to some of the observed behavioural differences in everyday communication in ASC.

Acknowledgements

We would like to thank the children and parents included in this study. We are also grateful for the support from Professor Guoli Yan and Professor Yinghong Han, all participating schools and the Yitong Autism Research and Service Centre of Tianjin, China.

Disclosure statement

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

Funding

This study was supported by the research fund from Jiangsu Planning Office of Philosophy and Social Science [23JYC011], Jiangsu Provincial Key Constructive Laboratory for Big Data of Psychology and Cognitive Science [72592162004G], and the Natural Science Foundation of the Higher Education Institutions of Jiangsu Province [22KJD180007].

Data availability statement

Data file and related analysing codes are available from the Open Science Framework: http://osf.io/rbaet/files/.

References

Akechi, H., Stein, T., Kikuchi, Y., Tojo, Y., Osanai, H., & Hasegawa, T. (2015). Preferential awareness of protofacial stimuli in autism. *Cognition*, *143*, 129–134. https://doi.org/10.1016/j.cognition.2015.06.016

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.).

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

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., & Minshew, N. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia*, *44*(1), 110–129. https://doi.org/10.1016/j.neuropsychologia.2005.04.002

Benson, V., Piper, J., & Fletcher-Watson, S. (2009). Atypical saccadic scanning in autistic spectrum disorder. *Neuropsychologia*, *47*(4), 1178–1182. https://doi.org/10.1016/j.neuropsychologia.2008.11.019

Bindemann, M., Burton, A. M., Hooge, I. T., Jenkins, R., & de Haan, E. H. (2005). Faces retain attention. *Psychonomic*

Bulletin & Review, *12*(6), 1048–1053. https://doi.org/10.3758/bf03206442
Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological Psychiatry*, *74*(3), 195–203. https://doi.org/10.1016/j.biopsych.2012.11.022
Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences*, *16*(4), 231–239. https://doi.org/10.1016/j.tics.2012.02.007
Colombo, J., & Cheatham, C. L. (2006). The emergence and basis of endogenous attention in infancy and early childhood. *Advances in Child Development and Behavior*, *34*, 283–322. https://doi.org/10.1016/S0065-2407(06)80010-8
Crouzet, S. M., Kirchner, H., & Thorpe, S. J. (2010). Fast saccades toward faces: Face detection in just 100 ms. *Journal of Vision*, *10*(4), 1–17. https://doi.org/10.1167/10.4.16
Dawson, G., Bernier, R., & Ring, R. H. (2012). Social attention: A possible early indicator of efficacy in autism clinical trials. *Journal of Neurodevelopmental Disorders*, *4*(1), 11. https://doi.org/10.1186/1866-1955-4-11
Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders*, *28*(6), 479–485. https://doi.org/10.1023/A:1026043926488
Del Bianco, T., Mazzoni, N., Bentenuto, A., & Venuti, P. (2018). An investigation of attention to faces and eyes: Looking time is task-dependent in autism spectrum disorder. *Frontiers in Psychology*, *9*, 2629. https://doi.org/10.3389/fpsyg.2018.02629
Dichter, G. S., & Belger, A. (2007). Social stimuli interfere with cognitive control in autism. *Neuroimage*, *35*(3), 1219–1230. https://doi.org/10.1016/j.neuroimage.2006.12.038
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
Donnelly, N., & Davidoff, J. (1999). The mental representations of faces and houses: Issues concerning parts and wholes. *Visual Cognition*, *6*(3–4), 319–344. https://doi.org/10.1080/135062899395000
Elsabbagh, M., Gliga, T., Pickles, A., Hudry, K., Charman, T., Johnson, M. H., & BASIS Team. (2013). The development of face orienting mechanisms in infants at-risk for autism. *Behavioural Brain Research*, *251*, 147–154. https://doi.org/10.1016/j.bbr.2012.07.030
Falck-Ytter, T. (2008). Face inversion effects in autism: A combined looking time and pupillometric study. *Autism Research*, *1*(5), 297–306. https://doi.org/10.1002/aur.45
Fischer, J., Koldewyn, K., Jiang, Y. V., & Kanwisher, N. (2014). Unimpaired attentional disengagement and social orienting in children with autism. *Clinical Psychological Science: A Journal of the Association for Psychological Science*, *2*(2), 214–223. https://doi.org/10.1177/2167702613496242
Fischer, J., Smith, H., Martinezâ-Pedraza, F., Carter, A. S., Kanwisher, N., & Kaldy, Z. (2016). Unimpaired attentional disengagement in toddlers with autism spectrum disorder. *Developmental Science*, *19*(6), 1095–1103. https://doi.org/10.1111/desc.12386
Freeth, M., Chapman, P., Ropar, D., & Mitchell, P. (2010). Do gaze cues in complex scenes capture and direct the attention of high functioning adolescents with ASD? Evidence from eye-tracking. *Journal of Autism and Developmental Disorders*, *40*(5), 534–547. https://doi.org/10.1007/s10803-009-0893-2
García-Blanco, A., López-Soler, C., Vento, M., Carmen García-Blanco, M., Gago, B., & Perea, M. (2017). Communication deficits and avoidance of angry faces in children with autism spectrum disorder. *Research in Developmental Disabilities*, *62*, 218–226. https://doi.org/10.1016/j.ridd.2017.02.002
George, N., Evans, J., Fiori, N., Davidoff, J., & Renault, B. (1996). Brain events related to normal and moderately scrambled faces. *Cognitive Brain Research*, *4*(2), 65–76. https://doi.org/10.1016/0926-6410(95)00045-3
Gong, X., Huang, Y. X., Wang, Y., & Luo, Y. J. (2011). Revision of the Chinese facial affective picture system. *Chinese Mental Health Journal*, *1*(25), 40–46.
Guillon, Q., Hadjikhani, N., Baduel, S., & Rogé, B. (2014). Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neuroscience & Biobehavioral Reviews*, *42*, 279–297. https://doi.org/10.1016/j.neubiorev.2014.03.013
Guillon, Q., Rogé, B., Afzali, M. H., Baduel, S., Kruck, J., & Hadjikhani, N. (2016). Intact perception but abnormal orientation towards face-like objects in young children with ASC. *Scientific Reports*, *6*(1), 22119. https://doi.org/10.1038/srep22119
Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25. https://doi.org/10.1007/s10803-005-0039-0
Hendry, A., Jones, E. J. H., Bedford, R., Gliga, T., Charman, T., Johnson, M., & the BASIS Team. (2018). Developmental change in look durations predicts later effortful control in toddlers at familial risk for ASD. *Journal of Neurodevelopmental Disorders*, *10*(1), Article 3. https://doi.org/10.1186/s11689-017-9219-4
Hopfinger, J., Buonocore, M., & Mangun, G. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, *3*(3), 284–291. https://doi.org/10.1038/72999
Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*(10–12), 1489–1506. https://doi.org/10.1016/S0042-6989(99)00163-7
Johnson, M. H. (2014). Autism: Demise of the innate social orienting hypothesis. *Current Biology*, *24*(1), R30–R31. https://doi.org/10.1016/j.cub.2013.11.021
Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*(1–2), 1–19. https://doi.org/10.1016/0010-0277(91)90045-6
Jones, E. J. H., Venema, K., Earl, R., Lowy, R., Barnes, K., Estes, A., Dawson, G., & Webb, S. J. (2016). Reduced

engagement with social stimuli in 6-month-old infants with later autism spectrum disorder: A longitudinal prospective study of infants at high familial risk. *Journal of Neurodevelopmental Disorders*, *8*(1), 7. https://doi.org/10.1186/s11689-016-9139-8

Kliegl, R., Wei, P., Dambacher, M., Yan, M., & Zhou, X. (2011). Experimental effects and individual differences in linear mixed models: Estimating the relationship 120 between spatial, object, and attraction effects in visual attention. *Frontiers in Psychology*, *1*, 238. https://doi.org/10.3389/fpsyg.2010.00238

Klin, A., & Jones, W. (2008). Altered face scanning and impaired recognition of biological motion in a 15-month-old infant with autism. *Developmental Science*, *11*(1), 40–46. https://doi.org/10.1111/j.1467-7687.2007.00608.x

Leppänen, J. M. (2016). Using eye tracking to understand infants' attentional bias for faces. *Child Development Perspectives*, *10*(3), 161–165. https://doi.org/10.1016/j.ridd.2017.02.002

Luna, B., Velanova, K., & Geier, C. F. (2008). Development of eye-movement control. *Brain and Cognition*, *68*(3), 293–308. https://doi.org/10.1016/j.bandc.2008.08.019

Moore, D. J., Reidy, J., & Heavey, L. (2016). Attentional allocation of autism spectrum disorder individuals: Searching for a face-in-the-crowd. *Autism*, *20*(2), 163–171. https://doi.org/10.1177/1362361315573637

Pavlou, K., Benson, V., & Hadwin, J. A. (2016). Exploring links between neuroticism and psychoticism personality traits, attentional biases to threat and friendship quality in 9-11-year-olds. *Journal of Experimental Psychopathology*, *7*(3), 437–450. https://doi.org/10.5127/jep.055316

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3–25. https://doi.org/10.1080/00335558008248231

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*(2), 160–174. https://doi.org/10.1037/0096-3445.109.2.160

Riby, D. M., & Hancock, P. J. B. (2009). Do faces capture the attention of individuals with Williams syndrome or autism? Evidence from tracking eye movements. *Journal of Autism and Developmental Disorder*, *39*(3), 421–431. https://doi.org/10.1007/s10803-008-0641-z

Richards, H. J., Benson, V., & Hadwin, J. A. (2012). The attentional processes underlying impaired inhibition of threat in anxiety: The remote distractor effect. *Cognition & Emotion*, *26*(5), 934–942. https://doi.org/10.1080/02699931.2011.630990

Rigby, S. N., Stoesz, B. M., & Jakobson, L. S. (2016). Gaze patterns during scene processing in typical adults and adults with autism spectrum disorders. *Research in Autism Spectrum Disorders*, *25*, 24–36. https://doi.org/10.1016/j.rasd.2016.01.012

Rosset, D. B., Rondan, C., Da Fonseca, D., Santos, A., Assouline, B., & Deruelle, C. (2008). Typical emotion processing for cartoon but not for real faces in children with autistic spectrum disorders. *Journal of Autism and Developmental Disorder*, *38*(5), 919–925. https://doi.org/10.1007/s10803-007-0465-2

Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology*, *56*(5), 356–374. https://doi.org/10.1016/j.jmp.2012.08.001

Shah, P., Gaule, A., Bird, G., & Cook, R. (2013). Robust orienting to protofacial stimuli in autism. *Current Biology*, *23*(24), R1087–R1088. https://doi.org/10.1016/j.cub.2013.10.034

Sumner, E., Leonard, H. C., & Hill, E. L. (2018). Comparing attention to socially-relevant stimuli in autism spectrum disorder and developmental coordination disorder. *Journal of Abnormal Child Psychology*, *46*(8), 1717–1729. https://doi.org/10.1007/s10802-017-0393-3

Swettenham, J., Baron-Cohen, S., Charman, T., Cox, A., Baird, G., Drew, A., Baron-Cohen, S., Rees, L., & Wheelwright, S. (1998). The frequency and distribution of spontaneous attention shifts between social and nonsocial stimuli in autistic, typically developing, and nonautistic developmentally delayed infants. *Journal of Child Psychology and Psychiatry*, *39*(5), 747–753. https://doi.org/10.1111/1469-7610.00373

Theeuwes, J., & Stefan, V. D. S. (2006). Faces capture attention: Evidence from inhibition of return. *Visual Cognition*, *13*(6), 657–665. https://doi.org/10.1080/13506280500410949

van der Geest, J. N., Kemner, C., Camfferman, G., Verbaten, M. N., & van Engeland, H. (2002). Looking at images with human figures: Comparison between autistic and normal children. *Journal of Autism and Developmental Disorders*, *32*(2), 69–75. https://doi.org/10.1023/a:1014832420206

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

Weaver, M. D., & Lauwereyns, J. (2011). Attentional capture and hold: The oculomotor correlates of the change detection advantage for faces. *Psychological Research*, *75*(1), 10–23. https://doi.org/10.1007/s00426-010-0284-5

Webb, S. J., Jones, E. J. H., Merkle, K., Namkung, J., Greenson, J., Murias, M., & Dawson, G. (2010). Toddlers with elevated autism symptoms show slowed habituation to faces. *Child Neuropsychology*, *16*(3), 255–278. https://doi.org/10.1080/09297041003601454

Wenban-Smith, M. G., & Findlay, J. M. (1991). Express saccades: Is there a separate population in humans? *Experimental Brain Research*, *87*, 218–222.

Westfall, J. (2015). *PANGEA: Power analysis for general ANOVA designs*. Unpublished manuscript. http://jakewestfall.org/publications/pangea.pdf

Wilson, C. E., Brock, J., & Palermo, R. (2010). Attention to social stimuli and facial identity recognition skills in autism spectrum disorder. *Journal of Intellectual Disability Research*, *54*(12), 1104–1115. https://doi.org/10.1111/j.1365-2788.2010.01340.x

Yu, M., Li, Y., Mo, C., & Mo, L. (2017). Newly learned categories induce pre-attentive categorical perception of faces. *Scientific Reports*, *7*(1), 1–9. https://doi.org/10.1038/s41598-017-14104-6

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 Disorder*, *50*(2), 500–512. https://doi.org/10.1007/s10803-019-04271-y