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Shifting visual attention to social and non-social stimuli in Autism Spectrum Disorders

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ABSTRACT

Background: Some studies find that individuals with Autism Spectrum Disorders (ASD) experience difficulties in disengaging their attention from one stimulus and shifting to another, but findings are mixed. It is possible that instead of being a domain-general characteristic of ASD, the attentional differences may be affected by participants' inherent interest in the conceptual content of the stimuli they are shifting from and towards.

Method: Children with ASD (n = 22) and age-matched typically developing (TD) children (n = 22) Children participated in a gap-overlap visual attention paradigm and saccadic reaction time was measured. The central fixation stimulus was a conceptually neutral picture (i.e., a landscape photo) and there were three kinds of peripheral stimuli: social (faces), common objects, and objects that reflect stereotypical circumscribed interests of individuals with ASD (e.g., trains). On overlap trials, the peripheral stimulus appeared while the central fixation remained on the screen, thus fixating the peripheral stimulus required disengaging from the central stimulus and shifting. On gap trials, there was no overlap which minimized the requirement of disengaging prior to shifting.

Results: Data from the overlap trials showed that ASD children had more difficulty than TD children in disengaging from the neutral fixation to focus on any peripherally presented stimulus. However, they were quicker to fixate non-social peripheral stimuli that were related to their circumscribed interests compared with either faces or common objects. In contrast, TD children were quicker to fixate faces relative to the other stimuli.

Conclusions: These findings suggest that ASD is characterized by general difficulties in attentional control that affect disengaging, though the strength of these effects depends on children's inherent interest in the peripheral stimulus.

1. Introduction

Many empirical studies have converged on the claim that individuals with autism spectrum disorders (ASD) have difficulties orienting to social stimuli (Darson et al., 2004; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Sacrey, Armstrong, Bryson, & Zwaigenbaum, 2014). These impairments in attention are thought to be associated with the developmental challenges that children with ASD face in social communication and social cognition (Sasson, 2006). An important question concerns whether these difficulties in social orienting are domain-general or domain-specific. That is, do individuals with autism had difficulties with reorienting

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their attention from any stimulus they are currently engaged with, to any alternative? Or do individuals with autism have special difficulties orienting toward uniquely social stimuli? The goal of this research is to use the gap-overlap paradigm to measure individuals' abilities to orient to social stimuli and to stimuli that autistic people typically find particularly interesting to address these fundamental issues.

1.1. The gap-overlap task

Orienting to any visual stimulus that lies outside one's current attentional focus requires two potentially separable components. First one must *disengage* from whatever currently occupies one's attention and then one must *shift* to the peripheral stimulus (Posner & Cohen, 1984; Sacrey et al., 2014). These two components are often assessed independently in a paradigm known as the "gap-overlap" task. In this task, a stimulus is presented at a central fixation point and then after a delay, another stimulus appears in the periphery. On "gap" trials, the central stimulus disappears prior to the onset of the peripheral stimulus. On "overlap" trials, the central stimulus remains on the screen for the onset of the stimulus. The participant's task is to detect the position of the peripheral targets, and the dependent measure is saccadic reaction time (SRT). The logic is that although both gap and overlap trials require *shifting* attention, only the overlap trials require *disengagement* from the central stimulus (Sacrey et al., 2014; van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2001; Zwaigenbaum et al., 2005). Thus, the difference in saccadic reaction time during overlap trials compared to gap trials is called the *disengagement cost*, or the *gap effect* (Fischer, Koldewyn, Jiang, & Kanwisher, 2014; van der Geest et al., 2001).

1.2. Evidence for difficulties in disengaging from central stimulus

To date the evidence is mixed on the question of whether individuals with ASD have impairments in either disengaging or shifting attention to peripheral stimuli (Elsabbagh et al., 2009, 2013; Goldberg et al., 2002; Kawakubo et al., 2007; Landry & Bryson, 2004; for a review see Sacrey et al., 2014). Landry and Bryson (2004) used eye tracking during a gap-overlap paradigm with content-neutral stimuli (i.e., colored rectangles) and found that children with ASD took almost three times longer than controls to initiate an eye movement towards a peripheral stimulus on overlap trials, but no group differences emerged on gap trials. In another study, using a green light as both the central and peripheral stimulus, Goldberg et al. (2002) found that adolescents (aged 12–18 years) with high-functioning ASD had significant longer saccade reaction time in both gap and overlap trials relative to typically developing adolescents matched by age, gender and IQ. Evidence further confirming that the difficulties experienced by individuals with ASD pertain to *disengaging* from the central stimulus also comes from some electrophysiological studies. In an event-related potential (ERP) study of Kawakubo et al. (2007), central and peripheral stimuli included pictures of animals (e.g., dogs), everyday objects (e.g., glasses) and vehicles (e.g., car). They found that adults with ASD have higher pre-saccadic positivity under the overlap condition than the control group. The authors concluded that autistic people demonstrated higher and longer activities as indexed by pre-saccadic positivity in the brain to reach a threshold for executing the saccade to the peripheral stimuli, which suggests that individuals with autism had specific deficits in endogenous attentional disengagement. Taken together, these findings suggest that ASD may be characterized by longer saccadic reaction time to peripheral stimuli relative to control groups, indicating individuals with ASD suffer some difficulties in disengaging their attention from central fixation stimuli.

1.3. Evidence for no differences in disengagement or shifting

In contrast, when the stimuli in used in the gap-overlap task are less neutral, some studies report no evidence of disengagement or shifting impairments in ASD. For example, Kelly, Walker, and Norbury (2013) used a smiley face as their central stimulus and cartoon monsters as their peripheral stimuli and found no significant difference in the saccade latencies in the gap and overlap trials between the autistic children aged 8–14 and controls. More recently, Fischer et al. (2014) conducted a study with 44 children aged 5–12 with high-functioning ASD, in the gap-overlap paradigm using either social images (e.g., faces) or nonsocial images (e.g., fruits, vegetables, or trains) as the central stimuli and peripheral stimuli. They found that there was no significant difference in the SRT for either gap or overlap trials and no difference in disengagement cost between the children with ASD and the typically developing gender- and IQ-matched controls. Based on these results the authors suggested that children with high-functioning ASD have largely intact attentional disengagement and social orienting.

1.4. Intrinsic interest of the central or peripheral stimulus

To make sense of these inconsistent results, Sacrey et al. (2014) proposed that the social nature of the central stimulus may affect typically-developing individuals' abilities to disengage more than it does autistic individuals. In support of this possibility, Kikuchi et al. (2011) (in Experiment 1) found that when faces were used as a central fixation, typically-developing individuals had a larger gap effect than did autistic individuals. However, there were no differences when a non-face object was used as the central fixation. The authors suggested that, the salience of face affects the disengagement cost of typically developing children but not for children with ASD (see also Kelly et al., 2013). A similar finding was reported in work by Fischer et al. (2014), who showed that individuals with ASD had larger gap effects for non-social versus social stimuli, whereas the opposite was true for typically developing children (though, in both cases p-values fell just short of significance). These findings suggest that the stimulus type in the central fixation point may be an important factor influencing the results of gap-overlap studies.

For similar reasons, the inherent interest of the peripheral target might also be associated with SRT for the participants with ASD. According to the social motivation theory of autism, individuals with ASD are proposed to be less intrinsically interested in social stimuli, which itself leads to irregular orienting to those stimuli in experimental tasks (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012). For example, when children with ASD free view static photographs of everyday social interactions, they spent more time in fixating at the background rather than the characters as the typically developing children do (Riby & Hancock, 2008). With respect to the gap-overlap task specifically, these findings raise the possibility that, along with the qualities of the central stimulus, the attraction of peripheral social and non-social stimuli might affect the magnitude of the gap effect and how performance in ASD populations may compare with control populations. Specifically, comparing typically developing children to individuals with ASD on stimuli that are known to be, say, less interesting to ASD individuals than they are to typically developing individuals, may lead to a mischaracterization of potential differences in domain-general capacities for attentional disengagement and shifting. Put another way, it is important to ensure that any apparent difficulties in shifting to peripheral targets in the gap-overlap paradigm are attributable to domain-general processes, as opposed to a more domain-specific interest in the centrally presented stimulus or lack of interest in the peripheral stimuli (see also Bourgeois, Chelazzi, & Vuilleumier, 2016).

To address these issues, we recorded the saccadic reaction times from a group of ASD individuals and a group of age-matched controls in a gap-overlap paradigm that paired a neutral stimulus (a simple landscape) with three different kinds of peripheral stimuli: 1) social stimuli (human portraits), 2) pictures of things that correspond with ASD individuals' so-called "circumscribed interests" (objects such as trains that typically capture the interest of ASD individuals, see Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008), and, 3) objects that lie outside of circumscribed interests (e.g., glove). If children with ASD have domain-general difficulties with disengaging attention, they will have a larger gap-effect in the gap-overlap task compared to typically developing children regardless of whether the peripheral stimulus is social, one that they are particularly interested in, or neutral. Alternatively, if the difficulty is attributable to a domain-specific lack of interest in social stimuli, per se, then we might see a pattern whereby ASD individuals have larger gap effects for social stimuli relative to neutral stimuli or items they are particularly interested in.

2. Method

2.1. Participants

Twenty-two children with ASD and 22 typically developing (TD) children participated in this study. All children with ASD were diagnosed in a psychiatric hospital, and met criteria for a diagnosis of autism on both the DSM-IV (American Psychiatric Association, 2000) and CCMD-3 (Chinese Psychiatry Association, 2001). The children with ASD, 5 of whom were diagnosed with Asperger syndrome, and 17 with autism, were recruited from a special education school in the city of Wuhan; the TD children were recruited form a primary school attached to Central China Normal University. The two groups were matched on chronological age and gender. None of the TD children had a diagnosis of a psychiatric or developmental disorder. Due to low sampling rates in eye tracking experiments, four children with ASD and 1 TD child were excluded from the analyses. Thus the final sample included 18 children with ASD (14 males) and 21 TD children (16 males). Children in both groups had normal or corrected-to-normal vision. All participants completed the Peabody Picture-Verbal Test- Revised (PPVT-R Chinese version, revised from Dunn & Dunn, 1981) and Childhood Autism Rating Scale (CARS Chinese version). The PPVT is a measure of receptive vocabulary, which ensured that participants understood the experiment instructions. Written informed consent was obtained from parents or teachers, and participants received a gift for their participation. All experimental protocols were approved by the Ethics Committee of Central China Normal University. Participant information and t-tests of group differences are shown in Table 1.

2.2. Materials and apparatus

Materials included four types of pictures: landscapes, objects related to circumscribed interests (CI), objects not related to circumscribed interests (no-CI), and social objects. The landscape pictures were neutral photos selected at random from the travel photo albums of 100 friends. All the pictures were uploaded on the Questionnaire Star Website and raters were asked to evaluate the images on the basis of three dimensions: pleasure, arousal, and dominance. From these ratings we selected 52 pictures which were recognized as "neutral landscapes" by more than 75% of raters. Of these, 48 scenes were used in the experimental procedure and 4 were used in a practice phase.

Stimuli included 8 CI pictures, 8 non-CI pictures and 8 facial portraits. The CI and non-CI pictures were selected on the basis of

Table 1
Age, PPVT and CARS Scores for ASD and TD Participants.

	ASD (n = 18)		TD (n = 21)			
	$M \pm SD$	Range	$M \pm SD$	Range	t-value	p-value
Age(month)	80.78 ± 29.18	50–140	77.95 ± 5.57	66–88	0.435	0.666
PPVT	74.50 ± 34.49	47–152	96.29 ± 21.32	57–125	-2.41^{*}	0.021
CARS	31.28 ± 4.36	21–37	15.81 ± 2.60	15–25	12.009^{***}	0.000

Note: $^{*}p < 0.05$, $^{***}p < 0.001$; PPVT: Peabody Picture Verbal Test; CARS: Children Autism Rating Scale.

previous research examining circumscribed interests in children with ASD (Sasson, Elison, Turner-Brown, Dichter, & Bodfish, 2011). The eight CI pictures included images related to the following objects: trains, buses, airplanes, computers, buildings, appliances, equipment, road signs and sports equipment. The eight non-CI pictures included: clothes, hats, gloves, bags, furniture, plants, bathroom facilities and other stimuli types (Sasson et al., 2011). All CI and non-CI stimuli were non-social. The social stimuli included eight portraits of happy young male and female models. All images were processed with Photoshop CS6 to ensure identical luminance and saturation with 200 × 200 pixels.

Eye movement data were collected using a TobiiT120 eye tracker (Tobii Technology, Stockholm, Sweden) with a sampling rate of 120HZ. The stimuli were presented on a 17 in. TFT LCD color monitor with a resolution of 1024 × 768. Eye tracking data were recorded with a fixation criteria of gaze, namely more than 100 ms of viewing time at a fixation point within a 1° viewing angle. This was done in order to confirm the occurrence of eye-movements (Sasson et al., 2011, 2008).

2.3. Procedure

The experiment took place in two 1 h sessions that occurred on different days. In the first session, an experimenter administered the PPVT-R and the CARS. In the CARS, parents or teachers close to the children rated children's autistic symptoms. On the second day, we conducted the focal experiment. Children were tested in a quiet room in their school. Children were seated in front of an eye-tracking monitor with their eyes approximately 60 cm from the center of screen.

After completing a five-point binocular calibration, the focal gap-overlap task was administered. For reach trial in the gap-overlap task, a blank screen was presented for 600 ms, followed by a landscape image was presented at the center of the monitor for 1 s, with a viewing angle of 7° × 7°. The key condition difference concerned the presentation of the peripheral stimulus vis-à-vis the central stimulus. In the *gap* condition, the central stimulus disappeared from the screen prior to the presentation of the peripheral stimulus. There was no delay between the disappearance of the central stimulus and the appearance of peripheral stimulus. In the *overlap* condition, the central stimulus remained on screen while the peripheral stimulus was presented. In both conditions, the peripheral stimulus was presented either to the left or the right of the central stimulus location with a viewing angle of 7°×7° (Eccentricity = 14°). The peripheral stimulus remained on the screen for 3 s, after which a new trial began. Landscape images were paired randomly with peripheral objects.

Gap and overlap trials were separated and presented in two separate blocks, each consisting of 2 practice trials and 24 test trials. Participants received one block of gap trials and one block of overlap trials, and the block that came first was randomized across participants. In each block of trials (gap and overlap), there were 8 CI, 8 non-CI and 8 social stimuli, presented in a random order. There was a 5 min break between the two blocks. The eye-tracking system recorded the SRT for the CI, non-CI, and social stimuli presented in the peripheral area (See Figs. 1 and 2).

2.4. Data processing

We used a rectangular tool to define the area of the region of interests (ROI) for the eight CI, eight non-CI and eight social images in the free viewing task. Saccadic reaction times (SRT) were defined as the length of time from the onset of the peripheral stimulus to the first gaze fixation within the stimulus ROI. SRT data were submitted to a mixed-model ANOVA to analyze the effect of stimulus type and experimental group on the shift and disengagement of attention.

3. Results

The raw data were processed using the Tobii Studio software before further analyses with SPSS17.0. An initial check was done to ensure that participants had adequate eye-tracking data for analysis. In line with prior work, we used a criteria of allowing participants no more than 25% missing data from the eye-tracking record (see e.g., Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009). Based on these criteria, four children with ASD and one TD child were excluded from further analysis. Preliminary analyses showed no evidence of correlation between SRT and children's receptive language (i.e., PPVT) and so PPVT was not included as a

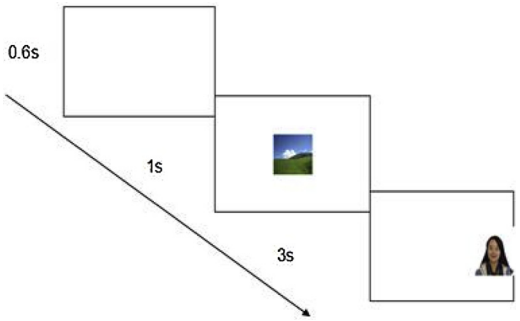

Fig. 1. The example of gap condition (shift of attention) with the head portrait image as the peripheral stimulus.

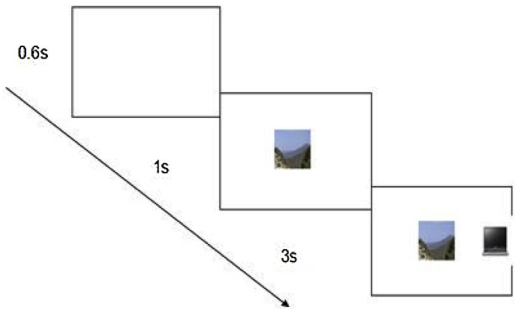

Fig. 2. The example of over-lap condition (disengagement of attention) with the computer image as the peripheral stimulus.

covariate in subsequent analyses.

3.1. Mixed-design ANOVA

3.1.1. SRT

A mixed-design ANOVA with SRT as the dependent variable, experimental group (ASD vs. TD) as a between-subjects variable, and stimulus type (social, CI and non-CI) and task type (gap vs. overlap) as within-subjects variables showed that there was a significant main effect of group, $F(1, 37) = 11.566$, $p = 0.002$, partial $\eta^2 = 0.238$. Overall, there were longer SRTs in children with ASD relative to TD controls ($M_{ASD} = 0.636$ s, $SD = 0.038$ s; $M_{TD} = 0.460$ s, $SD = 0.035$ s). There was also a significant main effect of stimulus type, $F(2, 74) = 7.413$, $p = 0.001$, partial $\eta^2 = 0.167$. Post-hoc tests showed SRTs to CI stimuli ($M_{CI} = 0.491$, $SD = 0.024$ s) were faster than to non-CI stimuli ($M_{non\text{-}CI} = 0.602$, $SD = 0.034$ s, $p < 0.01$). There was also a near-significant tendency for SRTs to be faster to the social stimuli ($M_{social} = 0.551$, $SD = 0.033$ s, $p = 0.067$) than to the non-CI stimuli.

These main effects were somewhat qualified by a group × stimulus type interaction effect, $F(2, 74) = 7.395$, $p = 0.001$, partial $\eta^2 = 0.167$. Follow-up simple effects analyses showed that there was no significant group difference in SRTs to CI stimuli ($M_{ASD} = 0.524$ s, $SD = 0.035$; $M_{TD} = 0.458$ s, $SD = 0.032$), $F(1, 37) = 1.94$, $p = 0.17$. However, relative to the TD group, ASD participants were slower to orient to both non-CI stimuli [$M_{ASD} = 0.746$ s, $SD = 0.050$ s; $M_{TD} = 0.458$ s, $SD = 0.047$ s], $F(1, 37) = 17.567$, $p < 0.001$, and social stimuli [$M_{ASD} = 0.637$ s, $SD = 0.049$ s; $M_{TD} = 0.465$ s, $SD = 0.045$ s], $F(1, 37) = 6.776$, $p = 0.013$. See Fig. 3.

The ANOVA showed a significant main effect of task type, $F(1, 37) = 15.816$, $p < 0.001$, partial $\eta^2 = 0.299$. As expected SRT of overlap trials was significantly longer than that of gap trials ($M_{gap} = 0.50$ s, $SD = 0.025$; $M_{overlap} = 0.596$ s, $SD = 0.031$). Importantly, there was also a significant group × attentional task type interaction effect, $F(1, 37) = 5.053$, $p = 0.031$, partial $\eta^2 = 0.120$. Simple effects analyses revealed that there was a significant difference for SRT between gap and overlap tasks for children with ASD, $F(1, 37) = 17.99$, $p < 0.001$, $M_{gap} = 0.56$ s, $M_{overlap} = 0.71$ s, but no significant difference for the TD group, $F(2, 36) = 1.62$, $p = 0.21$.

3.2. The effect of stimulus type on gap and overlap trials

Although the omnibus ANOVAs did not reveal significant three-way interactions to suggest that different trial types had differential effects on the gap and overlap task, we conducted exploratory analyses to gain direct evidence on this question of theoretical interest. We did this by conducting mixed group × stimulus type ANOVAs for the gap and overlap tasks separately. For the gap

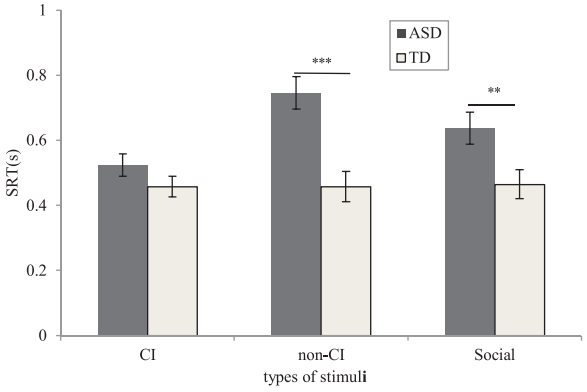

Fig. 3. The SRTs of the two groups in the gap-overlap task.

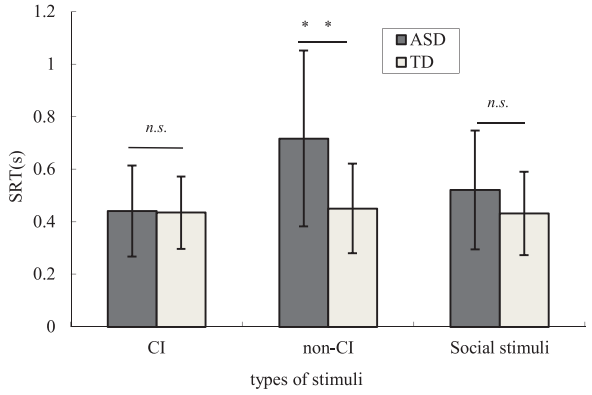

Fig. 4. SRTs to three types of stimuli in the gap condition for ASD and TD.

condition, recapitulating the main analyses, there was a significant effect of group, F (1, 37) = 5.616, p = 0.023, and a significant effect of item, F (2, 74) = 8.355, p = 0.001), partial η^2 = 0.184. But importantly there was also a significant stimulus type by group interaction, F (2, 74) = 6.407, p = 0.003, partial η^2 = 0.148. As illustrated in Fig. 4, post-hoc follow up analyses revealed significant group differences in SRT for the non-CI stimuli, but not for CI and social stimuli, though social stimuli were in the expected direction.

For the overlap condition, also recapitulating the main analyses, there was a significant main effect of group, F (1, 37) = 13.54, p = 0.001, partial η^2 = 0.268, and a near-significant main effect of stimulus type, F (2, 74) = 2.386, p = 0.099, partial η^2 = 0.061. More important, the interaction between group and stimulus type fell just shy of standard significance criteria, F (2, 74) = 2.621, p = 0.079, partial η^2 = 0.066. Exploratory post-hoc tests showed that group effects were particularly pronounced for non-CI and social stimuli, and smaller and non-significant, though in the same direction, for CI stimuli (see Fig. 5).

Taken together, these findings suggest that group differences in orienting may be somewhat more sensitive to differences in stimulus type than are group differences in disengaging.

3.3. Age effects

The ASD and the TD samples included participants across a wide range of ages. To explore whether participants ages affected their SRT in any of the conditions we tested, we conducted preliminary correlation analyses. For individuals in the TD group, we observed mostly weak and moderate negative correlations between age and SRT, though, none reached statistical significance (rs = −0.35 to 0.06, ps = 0.12–0.86). For individuals in the ASD group, we observed moderate and strong correlations between age and SRT, with two reaching statistical significance (rs = −0.21 to −0.54, ps = 0.02–0.40). Thus, there was a general trend in both groups that older individuals had faster SRTs. To determine whether this trend interacted with our group effects (as reported above) we conducted a series of regression analyses in which the SRT in each of the conditions was predicted by group, age, and the group by age interaction. Results showed that the group by age interaction was not significant in any of these analyses (ps = 0.39–0.96). These findings provide confidence that these differential correlations with age did not significantly change the nature of the group effects that we reported above.

4. Discussion

This study examined ASD and TD children's performance in the gap-overlap paradigm to better understand how their abilities to

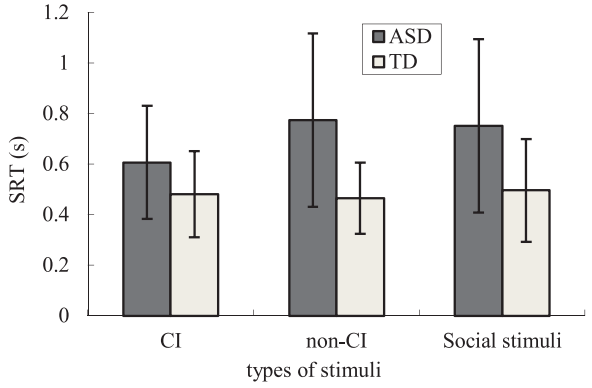

Fig. 5. SRTs to three types of stimuli in the overlap condition for ASD and TD.

disengage and shift attention from a central fixation can be affected by the stimuli that they are shifting toward. Compared to typically developing children, there was evidence that participants in the ASD group had a larger "gap effect" – across all kinds of stimuli participants with ASD had took longer to shift in the overlap condition than in the gap condition than did participants in the TD condition. These findings suggest that ASD may be characterized by a domain-general difficulty with attentional disengagement. Yet, there was also evidence that ASD children's attentional shifting and disengagement, in both gap and overlap trials, was affected by the type of stimulus that was in the periphery. Objects related to the ASD children's CIs were associated with shorter SRTs than non-CI objects and social stimuli. Indeed, across task types, ASD children's SRTs to CI objects was similar to that of their TD counterparts.

This study provides further evidence for the argument that ASD is characterized to some extent by difficulty in attentional disengagement. These findings are essentially consistent with other studies in the field (e.g., Goldberg et al., 2002; Landry & Bryson, 2004) which found longer saccadic delay in gap, baseline and overlap trials in the children with high-functioning ASD than control group. Yet, these findings are in contrast to other work that has found little evidence for a group difference in attentional disengagement and shifting (e.g., Fischer et al., 2014; Mosconi et al., 2009; Schmitt, Cook, Sweeney, & Mosconi, 2014). Although we are unclear as to why these discrepancies might have obtained, we speculate that one possibility is differences in the IQ of the ASD groups used in the different studies. For example, in the study by Fischer et al. (2014), the participants had similar higher IQ as typically developing children. The same was true for the participants in the Schmitt et al. (2014) study, the individuals with ASD and controls were matched in nonverbal IQ, and the mean of full scale IQ of individuals with ASD was near the average level of a TD group. In a systematic review of this literature, Sacrey et al. (2014) found strong evidence that IQ affected attentional disengagement in individuals with ASD. We agree with these authors that better understanding of the effects of IQ may help understand some of the heterogeneity of findings regarding group differences on the gap-overlap task.

Although the findings were most consistent with the conclusion that ASD is characterized by a broad, domain-general difficulty in attentional disengagement and shifting, there was also some evidence that the nature of the peripheral stimulus modulated this effect. Specifically, there were no significant differences between ASD and TD groups on gap trials when the peripheral stimuli were related to circumscribed interests of individuals with ASD. Moreover, individuals with ASD performed better on overlap trials when the peripheral stimuli were CI stimuli as compared with non-CI and social stimuli. These findings are consistent with previous research which has shown that individuals with ASD refocus their attention more quickly to CI stimuli like those used here as compared with other kinds of stimuli (e.g., Sacrey et al., 2014; Sasson et al., 2008). Perhaps more important, these findings confirm that stimulus interest and salience affects the specific characterization of the magnitude of the attentional shift and disengagement in ASD (Sacrey et al., 2014).

More generally, these findings support the view that, instead of being seen strictly as a domain-general capacity that applies equally across all stimuli, the flexible shifting of attention is affected by the motivational value of the conceptual content that one is both disengaging from and shifting toward (Bourgeois et al., 2016). With respect to ASD specifically, our findings are consistent with two other studies showing that inherent interest in the conceptual content of visual stimuli affects flexible attention in individuals with ASD (Chevallier et al., 2015; McSorley, Morriss, & van Reekum, 2017).

Our findings also have an important implication for extant theories of social attention impairment in ASD. Some have proposed that individuals with ASD have specific difficulties in orienting to social stimuli. Our findings do not comport with this view, in that we also found that individuals with ASD were also slow to fixate non-CI objects that appeared in the periphery. On overlap trials, which first required disengaging from a central fixation, ASD individuals had equal SRTs for subsequently fixating social and non-CI peripheral stimuli. Perhaps even more interesting, there was no difference between the ASD and TD groups in fixating social stimuli on the gap trials. Together, this pattern of results provide evidence for the view that ASD may have difficulty flexibly shifting their attention to a peripheral stimulus, especially when the stimuli that they are switching to are not of great inherent interest. However, social stimuli are not the only items that reveal this more domain-general difficulty.

Two results in our study should be discussed to better understand the attentional difficulties that may be characteristic of ASD. The first is that even in gap trials that putatively do not require disengaging prior to switching, individuals in the ASD group tended to show longer SRTs than did individuals in the TD group. This result was unexpected given the prior literature that typically does not show differences on gap trials (e.g., Fischer et al., 2014; Landry & Bryson, 2004). One possibility is that this is because of our specific inclusion of non-CI as compared with CI and social stimuli. The group effect on gap trials was driven largely the ASD group taking substantially longer to shift toward non-CI stimuli on gap trials relative to both CI and social stimuli. It seems possible that the inclusion of this category of stimuli as comparison created a context within which the non-CI and social stimuli were substantially less motivating and thus, less worthy of the attention of our ASD participants. Further work is necessary to think not only about how specific stimuli drive attentional shifting, but also about how stimulus context might play an important role as well.

A second puzzling finding was that we did not find significant evidence for a gap effect in the TD group, though such an effect is typically found. We suspect that this result may be attributable to the timing of stimulus presentation on the gap trials. In pilot work, we found that the fixations of children with ASD tended to drift during the brief blank screen (e.g., 250 ms) that normally comprises the ISI on gap trials. We reasoned that this tendency for gaze to drift could artificially affect the SRT estimates for fixating peripheral in the ASD group because their eyes would not be starting in the same place each time. Thus, we modified the paradigm from the traditional method such that the peripheral stimulus appeared at the same time when central stimulus disappeared (see also Fischer et al., 2014). Although we still observed a reliable gap effect in the ASD group, this change may have lengthened SRTs for gap trials and caused them to be somewhat more like overlap trials for the control children.

An important question concerns the underlying cognitive or computational factors that contribute to the domain-general challenges in attentional deployment that we observed. One possibility is that they are a consequence of a broader impairment in

executive functioning (Padmanabhan et al., 2015; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009; Sinzig, Vinzelberg, Evers, & Lehmkuhl, 2014; Snijders, Milivojevic, & Kemner, 2013). Executive functioning difficulties have long been proposed to be characteristic of ASD, and a recent meta-analysis confirms that across all ages, individuals with ASD have difficulty on behavioral tasks that rely on executive functioning, including working memory, response inhibition, flexibility, planning and fluency (see Demetriou et al., 2018). Although these executive functioning tasks tend to measure higher-level, or "aggregate" EF abilities (see e.g., Bardikoff & Sabbagh, 2017), there is reason to believe that at least some of the underlying neurocognitive mechanisms that are important for these behavioral skills are also required for the flexible deployment of attention. This is especially true in the "overlap" trials of the gap-overlap task, where participants are required to first disengage from the central stimulus in order to shift their fixation to a stimulus on the periphery (see e.g., Keehn, Müller, & Townsend, 2013). Although to our knowledge there is no direct evidence that this is the case, there is work showing that ASD individuals are slower and make more errors in the tasks that require complex control of visual attention, such as the anti-saccade task which requires participants to move their eyes to a location on the opposite side of where a stimulus appears (e.g., Goldberg et al., 2002; Luna, Doll, Hegedus, Minshew, & Sweeney, 2007).

A second possible explanation for the difficulties we observed in flexible attentional deployment for the ASD group concerns more fundamental motor difficulties that result from neurodevelopmental abnormalities within the brainstem and cerebellum (Schmitt et al., 2014). Using kinematic analyses, Schmitt et al. (2014) found evidence of biomechanical abnormalities in executing saccades among individuals with ASD. Specifically, they found that participants with ASD took longer than controls to accelerate saccades to peak velocity, and overall peak saccade velocities were lower. Based upon these findings, they proposed that abnormal dynamics of visually-guided saccades in individuals with ASD was due to neurodevelopmental abnormalities in the cerebellum and brainstem, rather than a problem of cortically based neurocognitive control. It may be a research direction in the future to reveal the underlying mechanism of abnormal attention dynamics in gap-overlap tasks in individuals with ASD.

Several limitations of this study should be noted. The first is that our findings are based upon a relatively small sample size. This raises questions about both the generalizability of our positive findings, and the possibility that additional findings may have been statistically significant if we had adequate statistical power. Nonetheless, we believe that these findings add important information to this literature and provide a basis for conducting a larger scale study addressing these research questions. A second limitation is that we did not record and analyze the eye-tracking data during the first fixation to the central stimulus. Doing so would have helped to better understand how participants in both groups attended to the central fixation and whether any systematic features of fixation to that central stimulus affected SRTs to the peripheral stimuli. A third limitation was that participants' full-scale IQ was not measured, nor was the potential presence of co-morbid disorders such as ADHD or major depression. Having this additional information would help better understand how our findings compare to others in the extant literature. Finally, the stimuli that we designated as CI stimuli were based on stereotypical interests of individuals with ASD rather than the interests of specific individuals' with ASD. Thus, we cannot be sure that they found the CI stimuli (such as trains) more interesting than they did the non-CI stimuli, and that the extent to which that was true was different for the ASD group relative to the TD group. Future research should take greater care to develop individual profiles of explicitly rated interest in stimuli and use those profiles to predict SRTs in both ASD and TD groups.

Despite these limitations, our study extends the previous research findings and provides further new perspectives on the question of attentional deployment in individuals with ASD. In addition to indexing some important domain-general difficulties, findings from our study also provide evidence that the conceptual content of the stimuli that are involved have an impact on how the magnitude of these differences will be characterized. Although it is commonly thought that individuals with ASD have specific difficulties in shifting attention to social stimuli, our findings suggest that they take longer to shift to any stimulus class that lies outside their circumscribed interests. Thus, ASD may be characterized by general difficulties in attentional control, though the magnitude of these difficulties may depend on children's inherent interest in the stimuli involved.

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References

American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders* (4th edition). Washington, D. C: APA.

Bardikoff, N. F., & Sabbagh, M. A. (2017). The differentiation of executive functioning across development: Insights from developmental cognitive neuroscience. In N. Budwig, E. Turiel, & P. D. Zelazo (Eds.). *New perspectives on human development*.

Bourgeois, A., Chelazzi, L., & Vuilleumier, P. (2016). How motivation and reward learning modulate selective attention. *Progress in Brain Research, 229*, 325–342.

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.

Chevallier, C., Parish-Morris, J., McVey, A., Rump, K. M., Sasson, N. J., & Herrington, J. D. (2015). Measuring social attention and motivation in Autism Spectrum Disorder using eye-tracking: Stimulus type matters. *Autism Research, 8*(5), 620–628.

Chinese Psychiatry Association (2001). *The Chinese classification and diagnoses criteria of mental disorders – The third edition (CCMD-3)*. Jinan: Shandong Technology Press.

Darson, G., Toth, K., Abbott, R., Osterling, J., Munson, J., & Estes, A. (2004). Early social attention impairments in autism: Social orienting, joint attention, and attention to distress. *Developmental Psychology, 40*(2), 271–283.

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*, 479–485.

Demetriou, E. A., Lampit, A., Quintana, D. S., Naismith, S. L., Song, Y. J. C., & Pye, J. E. (2018). Autism spectrum disorders: A meta-analysis of executive function.

Molecular Psychiatry, 23, 1198–1204.
Dunn, L. M., & Dunn, L. M. (1981). *Peabody picture vocabulary test-revised.* Circle Pines, MN: American Guidance Service, Inc.
Elsabbagh, M., Volein, A., Holmboe, K., Tucker, L., Csibra, G., & Baron-Cohen, S. (2009). Visual orienting in the early broader autism phenotype: Disengagement and facilitation. *Journal of Child Psychology and Psychiatry, 50*, 637–642.
Elsabbagh, M., Gliga, T., Pickles, A., Hudry, K., Charman, T., & Johnson, H. M. (2013). The development of face orienting mechanisms in infants at-risk for autism. *Behavioural Brain Research, 251*, 147–154.
Fischer, J., Koldewyn, K., Jiang, Y. V., & Kanwisher, N. (2014). Unimpaired attentional disengagement and social orienting in children with autism. *Clinical Psychological Science, 2*(2), 214–223.
Fletcher-Watson, S., Leekam, S. R., Benson, V., Frank, M. C., & Findlay, J. M. (2009). Eye-movements reveal attention to social information in autism spectrum disorder. *Neuropsychologia, 47*, 248–257.
Goldberg, M. C., Lasker, A. G., Zee, D. S., Garth, E., Tien, A., & Landa, R. J. (2002). Deficits in the initiation of eye movements in the absence of a visual target in adolescents with high functioning autism. *Neuropsychologia, 40*, 2039–2049.
Kawakubo, Y., Kasai, K., Okazaki, S., Hosokawa-Kakurai, M., Watanabe, K., & Kuwabara, H. (2007). Electrophysiological abnormalities of spatial attention in adults with autism during the gap overlap task. *Clinical Neurophysiology, 118*, 1464–1471.
Keehn, B., Müller, R.-A., & Townsend, J. (2013). Atypical attentional networks and the emergence of autism. *Neuroscience & Biobehavioral Reviews, 37*(2), 164–183.
Kelly, D. J., Walker, R., & Norbury, C. F. (2013). Deficits in volitional oculomotor control align with language status in autism spectrum disorders. *Developmental Science, 16*, 56–66.
Kikuchi, Y., Senju, A., Akechi, H., Tojo, Y., Osanai, H., & Hasegawa, T. (2011). Atypical disengagement from faces and its modulation by the control of eye fixation in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 41*, 629–645.
Landry, R., & Bryson, S. E. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry, 45*(6), 1115–1122.
Luna, B., Doll, S. K., Hegedus, S. J., Minshew, N. J., & Sweeney, J. A. (2007). Maturation of execution function in autism. *Biological Psychiatry, 61*, 474–481.
McSorley, E., Morriss, J., & van Reekum, C. M. (2017). Eye spy with my little eye: Motivational relevance of visual stimuli guide eye-movements at different processing stages. *Biological Psychology, 123*, 8–14.
Mosconi, M. W., Kay, M., D'Cruz Seidenfeld, A. M. A., Guter, S., Stanford, L. D., & Sweeney, J. A. (2009). Impaired inhibitory control is associated with higher-order repetitive behaviors in autism spectrum disorders. *Psychological Medicine, 39*(9), 1559–1566.
Padmanabhan, A., Garver, K., O' Hearn, K., Nawarawong, N., Liu, R., & Minshew, N. (2015). Developmental changes in brain function underlying inhibitory control in Autism Spectrum Disorders. *Autism Research, 8*(2), 123–135.
Posner, M. I., & Cohen, Y. (1984). Components of performance. In H. Bouma, & D. Bowhuis (Eds.). *Attention and performance X* (pp. 531–556). Hillsdale, MI: Erlbaum.
Riby, D. M., & Hancock, P. J. B. (2008). Viewing it differently: Social scene perception in Williams syndrome and autism. *Neuropsychologia, 46*(11), 2855–2860.
Robinson, S., Goddard, L., Dritschel, B., Wisley, M., & Howlin, P. (2009). Executive functions in children with Autism Spectrum Disorders. *Brain and Cognition, 71*, 362–368.
Sacrey, L. A., Armstrong, V. L., Bryson, S. E., & Zwaigenbaum, L. (2014). Impairments to visual disengagement in autism spectrum disorder: A review of experimental studies from infancy to adulthood. *Neuroscience & Biobehavioral Reviews, 47*, 559–577.
Sasson, N. J. (2006). The development of face processing in autism. *Journal of Autism and Developmental Disorders, 36*(3), 381–394.
Sasson, N. J., Turner-Brown, L. M., Holtzclaw, T. N., Lam, K. S., & Bodfish, J. W. (2008). Children with autism demonstrate circumscribed attention during passive viewing of complex social and nonsocial picture arrays. *Autism Research, 1*(1), 31–42.
Sasson, N. J., Elison, J., Turner-Brown, L., Dichter, G. S., & Bodfish, J. (2011). Brief report: Circumscribed attention in young children with autism. *Journal of Autism and Developmental Disorders, 41*, 242–247.
Schmitt, L. M., Cook, E. H., Sweeney, J. A., & Mosconi, M. W. (2014). Saccadic eye movement abnormalities in autism spectrum disorder indicate dysfunctions in cerebellum and brainstem. *Molecular Autism, 5*, 47.
Sinzig, J., Vinzelberg, I., Evers, V., & Lehmkuhl, G. (2014). Executive function and attention profiles in preschool and elementary school children with autism spectrum disorders or ADHD. *International Journal of Developmental Disabilities, 60*(3), 144–154.
Snijders, T. M., Milivojevic, B., & Kemner, C. (2013). Atypical excitation-inhibition balance in autism captured by the gamma response to contextual modulation. *Neuroimage: Clinical, 3*, 65–72.
van der Geest, J. N., Kemner, C., Camfferman, G., Verbaten, M. N., & van Engeland, H. (2001). Eye movements, visual attention, and autism: A saccadic reaction time study using the gap and overlap paradigm. *Biological Psychiatry, 50*(8), 614–619.
Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience, 23*(2), 143–152.