Impaired prioritization of novel onset stimuli in autism spectrum disorder

Brandon Keehn and Robert M. Joseph
Boston University School of Medicine

Background: Deficiency in the adaptive allocation of attention to relevant environmental stimuli is an associated feature of autism spectrum disorder (ASD). Recent evidence suggests that individuals with ASD may be specifically impaired in attentional prioritization of novel onsets. Method: We investigated modulation of attention by novel onset stimuli in 22 children with ASD and 22 age- and IQ-matched typically developing (TD) children using a preview visual search task (Donk & Theeuwes, 2003). In preview search, a subset of search stimuli (old) is presented briefly before the remaining stimuli (new) with the effect that search times for targets appearing among the new elements are typically shorter than for those appearing among the old elements. Results: Whereas the TD group exhibited faster reaction time (RT) to targets occurring as novel search elements, the ASD group performed similarly in target new and old conditions, indicating impaired attentional prioritization of novel onsets. Group differences in eye-movement behavior, including fixation frequency and saccadic error for novel onset stimuli, were consistent with the RT findings. Attentional modulation by novel onsets varied inversely with social-communicative symptom severity in the ASD group. Conclusions: The results provide further evidence of reduced sensitivity to novel onsets in ASD, and suggest that impaired processing of dynamic stimuli, possibly associated with abnormalities in the dorsal visual processing stream, may be implicated in the core symptoms of ASD. Keywords: Autism, eye movements, reaction time, visual attention, visual search.

Although autism is diagnosed on the basis of impairments and anomalies in three core symptom domains, namely, communication, reciprocal social interaction, and repetitive and stereotyped interests and behaviors, abnormal modulation of attention is a well-documented associated feature of the disorder (Burack, Enns, Stauder, Mottron, & Randolph, 1997; Plaisted, 2000). Individuals with autism spectrum disorder (ASD) are often overly selective and focused in their attention (Burack, 1994; Mann & Walker, 2003) and are typically poor at allocating attention to relevant stimuli (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998).

Adaptive allocation of attention to relevant stimuli in the environment involves both top-down and bottom-up processes. Whereas top-down guidance of visual attention is voluntary and depends on task-relevant objectives represented in the mind of the observer, bottom-up control of visual attention is involuntary and is based on stimulus characteristics that are independent of the goals of the observer. Abrupt onset, as when a novel object suddenly appears where nothing was before, is one such stimulus characteristic and has been shown to be uniquely powerful in capturing attention (Jonides & Yantis, 1988).

In the first study to explicitly investigate attention to novel onsets in ASD, Greenaway and Plaisted (2005) found impaired modulation of attention by onset stimuli, but not by color stimuli, in two different experiments. The authors argued that a deficit in attentional prioritization of dynamic onsets was consistent with autistic deficits in processing social information, which is by nature dynamic and transient, and their findings converged with prior evidence of motion perception impairments implicating the dorsal visual processing stream in the neuropathology of autism (Milne et al., 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Spencer et al., 2000).

Our goal in the present study was to further investigate attentional modulation by novel onsets in ASD specifically in the context of visual search. Given that individuals with ASD tend to excel at visual search (e.g., O’Riordan & Plaisted, 2001; O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001), further evidence of an onset-related deficiency in this domain would be particularly compelling. In visual search, an observer looks for a target stimulus among an array of distractor stimuli and responds whether a target is present or absent. To assess attentional prioritization of novel onsets in visual search, we used a preview visual search task developed by Donk and Theeuwes (2003). In this task, a subset of search elements (‘old’) is briefly presented prior to the appearance of the remaining search elements (‘new’). When a target (blue H) is present, it either appears among the new distractors (blue As, green Hs) or, with equal probability, among the old distractors (also blue As, green Hs) through an isoluminant color change of an old element (green H to blue H) simultaneous with the presentation of the new elements. Using this paradigm, Donk and Theeuwes (2003) demonstrated that search times for

Conflict of interest statement: No conflicts declared.
new-element targets were significantly shorter than for old-element targets, indicating that new onsets were prioritized even though there was no benefit to task performance in doing so, and leading to the conclusion that the onset stimuli automatically captured the observers’ attention.

In the present study, we administered Donk and Theeuwes’ preview search task to a group of children and adolescents with ASD. We reasoned that if participants with ASD are impaired in the attentional prioritization of novel stimuli, they would exhibit a reduced RT advantage for new over old targets in comparison to typically developing children and adolescents. In addition to examining the effects of the main experimental manipulation on RT, we tracked participants’ eye movements during the entire search procedure to assess whether differences in looking behavior might accompany group differences in RT. As such, the eye-tracking data could provide an important source of convergent information on the modulation of attention by novel onsets. Finally, to evaluate Greenaway and Plaisted’s (2005) suggestion that deficiencies in processing transient stimuli may be linked to social-communicative symptoms in ASD, we examined associations between sensitivity to novel onsets and a behavioral observational measure of autism symptom severity. Evidence linking a specific attentional impairment to the core social-communicative symptoms in ASD would raise the possibility that deficits in attention modulation are not merely associated or secondary features of autism, but are of deeper etiological significance with regard to the defining symptoms of ASD and their neurobiological underpinnings.

Method

Participants

Participants were 22 school-age children and adolescents with ASD (19 males), all of whom were judged to meet DSM-IV criteria for autism or PDD-NOS by an expert clinician (second author), and an age-matched comparison group of 22 typically developing (TD) children (18 males). Clinical diagnoses were confirmed with the Autism Diagnostic Interview – Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003) and the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 1999). All children in the ASD group met diagnostic criteria for autism on the ADI-R, with the exception of two children who were one point below the diagnostic threshold in the repetitive behavior domain. On the ADOS, 17 children met criteria for a classification of autism, two met criteria for a classification of autism spectrum disorder (or PDD-NOS), and three met ADOS criteria for autism in the social domain, but were below threshold in the communication domain. The latter three children met full criteria for autism on the ADI-R. The ASD and TD groups were well matched on age (ASD: M = 14;4, SD = 2;11; TD: M = 14;4; SD = 2;8; t (42) = .2, p = .82) and on non-verbal IQ (ASD: M = 109, SD = 11; TD: M = 109, SD = 13; t (42) = .0, p = .96, but not on verbal IQ (ASD: M = 104, SD = 19; TD: M = 113, SD = 16; t (42) = 1.7, p < .10), as measured with the Kaufman Brief Intelligence Test – II (Kaufman & Kaufman, 2004). Informed consent was obtained from all research participants in accordance with the Boston University Medical Campus IRB.

Apparatus

The experiment was presented using E-Prime 1.1 software on a Pentium IV 3.2 GHz PC with a 19-inch LCD (refresh rate of 75 MHz). Test responses were registered using a PST serial response button box. Participants’ point of regard was monitored using an ISCAN Model ETL-500 head-mounted, pupil-corneal reflection tracking system that allowed participants to move their heads freely during the test procedure.

Stimuli

The target was a blue capital H and the distractors were green Hs and blue As drawn in isoluminant blue (22.3 cd/m²) and green (22.8 cd/m²) and displayed on a darker (11.3 cd/m²) gray background. At a viewing distance of 57 cm, each search element subtended a visual angle of .7 × .85°, and was randomly positioned on a 6 × 6 array of 2.2× 2.2° squares. Elements were randomly positioned within each square to produce layout irregularity. Either 6, 10, or 14 distractors, half green Hs and blue As, appeared in the preview frame (old elements) for 400 ms, after which the remaining 14 elements appeared in the onset frame (new elements). When a target was present, it occurred with equal probability as a new or as an old element, in which case a blue H replaced a green H when the onset frame appeared. See Figure 1.

Design

The experiment consisted of 192 trials, divided into 4 blocks. A target was present on half of the trials. Within each block, target presence (present, absent), target occurrence (as old element, as new element) and set size (20, 24, 28) were varied in pseudorandom order.

Procedure

The task was to respond via a dominant-hand, two-choice, button-box response as to whether a target was present or absent. Each trial began with a fixation cross presented alone for 1000 ms. With the cross remaining on the screen, the preview and onset stimuli were presented in succession. The stimuli remained on the screen until the participant responded or 7000 ms had elapsed. Participants were informed that the target appeared with equal frequency among the old and new elements and were instructed to respond as quickly as possible without making errors. Demonstration trials and 24 practice trials were administered with corrective feedback.
Results

In all RT analyses, medians were used to reduce the influence of outliers. In all figures, error bars represent one standard error of the mean.

Search performance

Error. A mixed-model ANOVA with the factors group, target presence, and set size was conducted on the raw error data. As can be seen in Figure 2, error was higher for present than absent trials, $F(1, 42) = 93.2, p < .001$, $\eta_p^2 = .69$, and increased with set size, $F(2, 84) = 4.6, p < .02$, $\eta_p^2 = .10$. There was no group difference in error rate, $F(1, 42) = .2$, nor were there any group interaction effects. A separate analysis including only present trials also showed no group differences in error between the target old and new conditions, $F(1, 42) = .03$. Correlational analyses revealed no speed-accuracy tradeoffs in either group.

Reaction time. A similar ANOVA was conducted on median RT for correct trials. As illustrated in Figure 3, RT was longer in target absent than target present trials, $F(1, 42) = 316.0, p < .001$, $\eta_p^2 = .88$, and increased as a function of set size, $F(2, 84) = 35.4, p < .001$, $\eta_p^2 = .46$. Both of these effects on RT (as well as on error) were expected based on the visual search literature. There was no main effect of group, $F(1, 42) = .2$, nor were there any group interaction effects. An additional ANOVA that included only target present trials showed that RT was faster when targets appeared as new elements than when they appeared as old elements, $F(1, 42) = 10.7, p < .01$, $\eta_p^2 = .20$, and that RT increased with set size, $F(2, 84) = 9.9, p < .001$, $\eta_p^2 = .19$. There was no main effect of group, $F(1, 42) = 1.1$, but there was a group x target occurrence interaction, $F(1, 42) = 9.5, p < .01$, $\eta_p^2 = .19$. Analysis of this interaction showed that the ASD group performed marginally faster than the TD group in the target old condition, $F(1, 42) = 3.6, p < .06$, $\eta_p^2 = .08$, but that the groups did not differ in the target new condition, $F(1, 42) = .0$.

Repeated measures ANOVAs conducted separately for each group addressed the critical issue of whether participants obtained an RT benefit in the target new condition. Whereas the TD group showed a sizeable RT advantage when targets were new relative to when they were old, $F(1, 21) = 18.3, p < .001$, $\eta_p^2 = .47$, the autism group performed similarly in the two conditions, $F(1, 21) = .02$. See Figure 4a.

Figure 1 Illustration of target present trials. The preview frame was displayed for 400ms (a) after which the onset frame appeared with a target at an old stimulus location (b) or a target occupying a new spatial location (c). Blue stimuli are represented in black and green stimuli in gray.

Figure 2 Percent error as a function of group, target presence, target occurrence, and set size.
Search slopes. The slope of the function relating median RT to set size reflects the RT cost (ms/item) of each additional distractor and is generally taken as a measure of search efficiency, with steeper slopes indicative of slower, less efficient search. Attentional prioritization of new elements would be expected to yield significantly shallower slopes for targets appearing among the new elements than those appearing among the old elements. In contrast, slopes would not be expected to differ between target old and new conditions for children who fail to prioritize novel onsets. In fact, for both groups, search slopes were shallower in the target new condition (ASD: 5.7, TD: 11.2) than in the target old condition (ASD: 26.5, TD: 34.5), F(1, 42) = 5.9, p < .05, ηp² = .12. These effects did not differ significantly between groups.

Eye-movement behavior

Eye-movement data were successfully collected for 19 of the 22 ASD participants and all TD participants. For the 400 ms preview frame, there were no differences between groups or between target old and new conditions for number of fixations per trial (M = 1.1) or mean fixation duration (M = 608 ms). The remaining analyses focused on eye movements during the onset frame for target present trials in order to determine if there were any group differences in looking behavior related to the target occurrence condition. One set of analyses examined fixations made anywhere in the search display, and included measures of fixation frequency and duration as well as latency and error of the first saccade. Additional analyses were conducted to examine differences in fixation frequency specifically to old versus new elements and to blue versus green elements.

Fixation frequency and duration. To count as a fixation, point of regard had to be maintained for at least 5 continuous data samples (80–85 ms at a sample rate of 60 Hz) within an area of 1° of visual angle. There was no main effect of group on fixation number, F(1, 39) = 1.6, but there was a marginally
significant group × target occurrence interaction, \( F(1, 39) = 3.7, p < .06, \eta^2_{p} = .09 \). Whereas the ASD group made an equal number of fixations on target old (\( M = 2.8 \)) and target new (\( M = 2.8 \)) trials, TD participants made more fixations on target old (\( M = 3.3 \)) than target new (\( M = 2.9 \)) trials, which was mirrored by their increased RT for the target old condition. There were no differences between groups, \( F(1, 39) = 2.1 \), or between old and new target conditions, \( F(1, 39) = .02 \), in fixation duration (\( M = 331 \) ms).

Latency and error of first saccade. Latency of first saccade was measured as the duration between the start of the onset frame and the time at which the first saccade was initiated. There were no group, \( F(1, 39) = .3 \), or other effects on latency of first saccade. Error of first saccade was measured as the distance between the first fixation on the onset frame and the target location. There was no main effect of group on saccade error, \( F(1, 39) = .6 \), but there was a significant interaction between group and target occurrence, \( F(1, 39) = 5.2, p < .05, \eta^2_{p} = .12 \), as illustrated in Figure 4b. A repeated measures ANOVA conducted separately for the TD group showed a main effect of target occurrence, \( F(1, 21) = 8.4, p < .01, \eta^2_{p} = .29 \), with decreased saccade error in the new condition. A similar analysis showed no difference between conditions in the ASD group, \( F(1, 18) = .1 \). This interaction mirrored the group × target occurrence interaction found for RT, as can be seen by comparing Figures 4a and 4b.

Fixations to old versus new elements. On each trial, there were either 6, 10, or 14 old elements and 14 new elements. For each fixation, we determined whether the closest element (within 2°) was old or new. As illustrated in Figure 5, in the target old condition, the ASD group made significantly fewer fixations than the TD group to old elements, \( F(1, 39) = 4.3, p < .05, \eta^2_{p} = .09 \), and new elements, \( F(1, 39) = 5.2, p < .05, \eta^2_{p} = .12 \). In contrast, in the target new condition, the groups did not differ in number of fixations to either old or new elements. These findings reflected the group differences in RT between the target old and new conditions.

A more informative comparison with regard to automatic prioritization of onset stimuli was the extent to which participants fixated new elements when the target was not present among them as compared to when it was. Within-group comparisons showed that the TD group fixated new elements in the old condition significantly more than they did in the new condition, \( F(1, 21) = 6.7, p < .02, \eta^2_{p} = .24 \), suggesting that attentional prioritization of novel onsets contributed to their longer RT when targets were among the old stimuli. In contrast, the ASD group fixated new elements in the target old condition no more than in the target new condition, \( F(1, 18) = .01 \).

Fixations to blue versus green elements. Because top-down, feature-based inhibition of old elements has been argued to facilitate attentional prioritization of new elements in preview search (Olivers, Humphreys, & Braithwaite, 2006), we analyzed fixations by stimulus color in order to assess possible group differences in inhibitory guidance of attention. This analysis revealed that participants were much more likely to direct attention to blue elements, which could be a target, than to green elements, which could never be a target, \( F(1, 39) = 142.6, p < .001, \eta^2_{p} = .79 \). Whereas participants with ASD made fewer fixations per trial to blue stimuli than TD participants (ASD: \( M = 1.0 \), TD: \( M = 1.3 \)), \( F(1, 39) = 4.2, p < .05, \eta^2_{p} = .10 \), consistent with their overall lower frequency of fixations, the number of fixations to green stimuli did not differ between the groups (ASD: \( M = .5 \), TD: \( M = .5 \)), \( F(1, 39) = .3 \). These findings indicated that feature-based inhibition of attention to green elements was strongly at play in this preview search paradigm and did not differ between groups.

Search behavior and autism symptom severity

Sensitivity to novel onset stimuli was measured by subtracting median RT for the target new from the target old condition. Positive old–new difference scores reflected faster RT for new relative to old targets. Symptom severity in ASD participants was assessed with Module 3 of the ADOS (Lord et al., 1999). The ADOS involves a series of experimenter-administered social occasions and ‘presses’ designed to provide quantitative observational ratings of communicative and social behaviors. Higher ADOS scores reflect increased symptom severity. Correlational analyses revealed that the old–new difference score was inversely related to communication, \( r(20) = -.62, p < .01 \), social, \( r(20) = -.47, p < .05 \), and combined communication and social, \( r(20) = -.59, p < .01 \), ADOS algorithm scores, demonstrating
that decreased sensitivity to novel onsets was associated with increased symptom severity in ASD participants. The old–new difference score was not significantly associated with the ADOS repetitive behavior algorithm score \( r(20) = -0.27 \).

To ensure that the relation between novel onset sensitivity and symptom severity was independent of age and IQ, additional correlational analyses were conducted. The old–new difference score was not correlated with age, \( r(20) = -0.01 \), verbal IQ, \( r(20) = 0.10 \) or nonverbal IQ, \( r(20) = -0.00 \), all \( p > 0.60 \), nor was ADOS social-communication score correlated with age, \( r(20) = -0.02 \), verbal IQ, \( r(20) = 0.08 \), or nonverbal IQ, \( r(20) = 0.26 \), all \( p > 0.20 \). Further, in partial correlations controlling separately for the effects of age, verbal IQ, and nonverbal IQ, the correlations between the old–new difference score and ADOS scores all remained at the same \( p \)-values as in the raw correlations.

**Discussion**

Two main findings emerged from this study. First, children with ASD exhibited impaired attentional prioritization of novel onset stimuli in visual search, which was evident in both their RT data and eye-movement behavior. Second, decreased sensitivity to novel onsets was associated with more severe symptoms in children with ASD. We discuss each of these findings in turn.

In contrast to their TD peers, children with ASD showed no difference in RT to search targets occurring as new elements as compared to targets occurring as old elements, indicating that their attention was not preferentially directed to novel onsets. Further, the different patterns of RT between groups were paralleled by group differences in eye movement behavior. When a target occurred as a new element, accuracy of first fixations with respect to the target location improved in the TD group, suggesting that attention was directed to new elements in the search array. In contrast, saccade accuracy did not differ between the new and old conditions in the ASD group, again suggesting that individuals with ASD did not selectively attend to newly appearing elements in the search array. In addition, TD participants made more fixations to new elements in the target old than in the target new condition, consistent with the conclusion that attentional capture by novel onsets lengthened their RT for old targets. In contrast, ASD participants fixated new elements no more in the target old than in the target new condition.

Greenaway and Plaisted (2005) previously reported impaired attentional modulation in children with ASD in tasks in which a single visual onset served as either a cue or a distractor for spatially allocating attention. Our results are in agreement with those of Greenway and Plaisted and extend them by demonstrating impaired modulation of attention by multiple novel onsets, in the context of a color-form conjunction task in which individuals with ASD typically excel (O’Riordan et al., 2001; O’Riordan & Plaisted, 2001), and by providing convergent eye-tracking evidence of differences in looking behavior in response to abrupt onsets in children with ASD. Together, these findings provide fairly compelling evidence of a specific anomaly of attention modulation that could explain a range of associated behavioral features of ASD, including tendencies toward over-selectivity and perseveration in attentional focus and weaknesses in orienting adaptively to relevant environmental stimuli. At a deeper level of explanation, it is also possible that impairments in attentional prioritization of dynamic stimuli could, as Greenaway and Plaisted (2005) have proposed, impede processing of social stimuli, which are by nature discontinuous and in constant flux. As such, impaired prioritization of onset stimuli may index neurocognitive differences in attention modulation that potentially contribute to the development of the social-communicative deficits that are essentially defining of ASD. Below, we consider this possibility further in relation to our finding of a link between onset sensitivity and ASD symptom severity.

Before turning to our second finding, we address some possible objections or caveats to our interpretation of the RT results from the preview search task. First, it could be argued that the lack of an RT benefit for ASD participants in the target new condition resulted not from a failure to prioritize new stimuli, but more basically from a failure to de-prioritize or disengage from old stimuli (Landry & Bryson, 2004; Townsend, Harris, & Courchesne, 1996). However, if this were the case, we would have expected to find a reversal of the typical preview effect in ASD, with faster detection of old than of new targets. Moreover, if attentional disengagement were a problem for the ASD participants in this study, we would have expected them to exhibit longer saccade latencies than TD participants, and they did not.

Second, there remains considerable debate regarding the neurofunctional mechanisms underlying the preview effect in visual search (Donk, 2006; Olivers et al., 2006), with evidence of both top-down and bottom-up control of attention, in part determined by the specific experimental parameters used. In the present study, we were specifically interested in automatic, bottom-up modulation of attention by dynamic stimuli in ASD. We therefore used a paradigm that specifically minimized the influence of voluntary, top-down inhibition of attention to old elements (Watson & Humphreys, 1997) by making inhibitory marking of old elements task-irrelevant, in so far as targets were as likely to appear among old as among new elements. Although we cannot rule out definitively that weaknesses in top-down inhibitory control contributed to the failure of participants with ASD to prioritize new search elements, our
eye-tracking analyses indicated that ASD participants were able to exercise strategic inhibition of attention, based on stimulus color, equally as well as TD participants. Further, in prior studies of negative priming, individuals with autism have been shown to have normal top-down attentional inhibition based on stimulus location (Brian, Tipper, Weaver, & Bryson, 2003) and stimulus identity (O’Riordan, 2000). These findings suggest that insensitivity to novel onsets in our ASD participants did not derive from an impairment of top-down inhibitory processes.

Finally, we found that children with ASD, like TD children, exhibited significantly shallower RT × set size slopes in the target new than in the target old condition. If children with ASD were insensitive to the onset of new elements, their slopes would not be expected to differ significantly between new and old conditions. Shallower slopes in the new condition could thus be taken as evidence that ASD participants, like our TD participants and healthy adults in other studies (Donk & Theeuws, 2003), selectively prioritized the new elements, making their search times relatively constant and independent of the number of old elements. However, inspection of the RT data suggests that the slope data may be misleading in this regard. For example, if participants with ASD prioritized novel onsets, it would be difficult to explain why their RT for new targets was slower than for old targets at the set size of 20 and no faster than for old targets at the set size of 24 (see Figure 3). In contrast, TD participants exhibited consistently faster RT for targets appearing as new elements across all set sizes in addition to a shallow RT × set size slope for the target new condition. Another consideration is the degree to which color-based inhibition may contribute to the differences in slopes between target new and target old conditions in the preview search paradigm we administered. Even in the absence of attentional prioritization of novel onsets, inhibition of attention to green elements, which was found to be operative in both groups, would be expected to result in decreased search efficiency in the target old relative to the target new condition. This is because color-based inhibition would lead participants to search among all of the blue elements before re-attending to the previously green element which becomes a target in the old condition. In contrast, in the new condition, inhibition of green elements leads to relatively more efficient discrimination of a novel blue target. Thus, feature-based inhibition may have been at least partly responsible for shallower slopes in the target new condition in both groups.

Children with ASD not only exhibited impaired sensitivity to abrupt onsets, but severity of social-communicative symptoms within the ASD group varied inversely in relation to onset sensitivity. In other words, the less attentionally responsive children were to abrupt onsets the more impaired they were in their social-communicative functioning, and vice versa. A particular strength of our measurement of onset sensitivity was that as a difference score it was independent of absolute level of processing efficiency, which could reasonably be expected to covary in a non-specific way with the degree of impairment in ASD or any behaviorally defined disorder. In a similar vein, the correlation between attention modulation by onsets and symptom severity was independent of IQ as well as age.

Evidence that impaired processing of dynamic onsets is directly related to symptom severity suggests that a basic attentional deficit, not specific to the social domain, could have explanatory power with regard to the causes and development of autistic social-communicative impairment, as Greenaway and Plaisted (2005) hypothesized. How might this link between an impairment in attention modulation and autism symptom severity be explained in terms of brain-level processes? As noted in the introduction, prior research has implicated the dorsal visual processing stream in the neuropathology of autism. Although there is considerable controversy as to the exact nature of the dorsal visual stream and associated motion processing impairments in autism, they appear to affect higher-level dorsal stream functions (Bertone et al., 2005; Dakin & Frith, 2005; Pellicano et al., 2005). These include non-social (or domain-general) processing functions earlier in the dorsal visual stream typically associated with human MT/V5, such as motion coherence detection (Milne et al., 2002; Pellicano et al., 2005; Spencer et al., 2000), as well as functions with profound social significance that are further down the dorsal visual stream and specifically associated with the superior temporal sulcus, such as perception of biological motion (Blake, Turner, Smoski, Pozdol, & Stone, 2003) and of eye gaze direction (Pelphrey, Morris, & McCarthy, 2005). This raises an intriguing question: Do domain-general abnormalities in attention modulation interfere with the development of higher-level social-information processing skills in autistic children over time, or do processing deficits for social and non-social stimuli reflect a common ontogenetic disturbance in brain formation that affects contiguous areas of dorsal visual cortex? Longitudinal behavioral research with young children at risk for autism complemented by pediatric neuroimaging studies will help to resolve these questions. Such research can tell us whether domain-general attentional abnormalities are causal or corollary in the development of autistic social-communicative deficits.

Author note
Brandon Keehn’s present address: Joint Doctoral Program in Language and Communicative Disorders, San Diego State University and University of California, San Diego.
Acknowledgements

This research was funded by NIDCD grant U19 DC 03610 (Project 1, PI: R. Joseph), part of the NICHD/ NIDCD Collaborative Programs of Excellence in Autism, and by NIMH grant K01 MH 073944 (PI: R. Joseph). We thank Rhynannon Bemis, David Black, Danielle Delosh, Alex Fine and Lin Themelis for assistance in data collection, Chris Connolly for assistance in compiling the eye-tracking data and, most of all, the children and families who generously participated.

Correspondence to

Robert M. Joseph, Department of Anatomy and Neurobiology, Boston University School of Medicine, 715 Albany St., L-814, Boston, MA, 02118, USA; Email: rmjoseph@bu.edu

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Manuscript accepted 31 March 2008