Unimpaired Attentional Disengagement and Social Orienting in Children with Autism

Jason Fischer*1, Kami Koldewyn*1, Yuhong V. Jiang2, & Nancy Kanwisher1
* These authors contributed equally to this work

1 Department of Brain and Cognitive Science and McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, MA
2 Department of Psychology, University of Minnesota, Minneapolis, MN

Abstract
Visual attention is often hypothesized to play a causal role in the development of autism spectrum disorder (ASD). Because attention shapes perception, learning, and social interaction, early deficits in attention could substantially impact the development of other perceptual and cognitive abilities. Here we test two key attentional phenomena thought to be disrupted in autism: attentional disengagement and social orienting. We find in a free viewing paradigm that both phenomena are present in high-functioning children with ASD (N=44; age 5-12 years) and are identical in magnitude to those in age- and IQ-matched typical children (N=40). While these attentional processes may malfunction in other circumstances, our data indicate that high-functioning children with ASD do not suffer from across-the-board disruptions of either attentional disengagement or social orienting. Combined with mounting evidence that other attentional abilities are largely intact, it seems increasingly unlikely that disruptions of core attentional abilities lie at the root of ASD.

Introduction
A central puzzle of autism is how a highly heritable disorder can produce such a specific and uneven cognitive profile, characterized not only by the signature deficit in social communication, but also by other apparently unrelated features like restricted interests (Szatmari et al., 2006) and the tendency to line up objects in a row (Turner, 1999). The most parsimonious theories of autism attempt to account for the full phenotype as resulting from a single, early-developing cognitive deficit. Featuring prominently among such theories is the idea that attention, our ability to selectively process a small subset of the sensory information impinging on our senses, is impaired in autism. Because attention is our window to the world, determining what we experience, respond to, and remember, an early-developing disorder of attention might have a far-reaching impact on cognitive development. Indeed, many have argued that the core clinical symptoms of autism spectrum disorder (ASD) – impairments in social interaction and communication – result from differences in how people with autism attend to the world during infancy and childhood (Dawson et al., 2004; Keehn, Müller, & Townsend, 2013; Loveland & Landry, 1986; Maestro et al., 2002; Toth, Munson, Meltzoff, & Dawson, 2006). Here we test two of the most widely-discussed attentional hypotheses of autism: that individuals with autism have atypical i) attentional disengagement, and ii) social orienting.

Impaired attentional disengagement is a prime suspect in the etiology of autism because
it could neatly explain many of the diverse symptoms of ASD. Landry and Bryson (Landry & Bryson, 2004) reported a striking disengagement impairment in ASD: they found that it takes children with ASD more than three times as long as typically developing (TD) controls to disengage attention from a visual stimulus. They likened the attentional capacity of their 6 year old children with autism to the “sticky” attention of typically developing 2-3 month olds (Hood & Atkinson, 1993; Johnson, Posner, & Rothbart, 1991), which, if true, could provide a powerful account for the well-known tendencies of children with ASD to develop restricted interests (Szatmari, et al., 2006), to fail to respond to their own name (Nadig et al., 2007), and to become fixated on single objects or tasks (Turner, 1999). The disengagement hypothesis features prominently in current theories of autism (Keen, et al., 2013; Menon, 2011).

However, the prominence of the theory has not been matched with equal empirical evidence. Studies that require attentional disengagement (those that instruct participants to make a saccade to new stimuli) have found equivalent or faster disengagement in ASD participants than controls (Kelly, Walker, & Norbury, 2013; Kikuchi et al., 2011; van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2001), suggesting that the fundamental mechanism of disengagement may be intact in ASD. Studies using free-viewing paradigms have supported a disengagement deficit in ASD, but two issues weaken this conclusion. Most significantly, these studies either tested children with low IQ (Landry & Bryson, 2004) or did not control for IQ due to the very young age of the participants (Elsabbagh et al., 2013; Zwaigenbaum et al., 2005). This confound is problematic because global developmental delay is associated with increased failure to disengage (Chawarska et al., 2010). Studies using free-viewing paradigms in infant siblings of children with ASD have reported slow disengagement (Elsabbagh et al., 2013; Elsabbagh et al., 2009), but used stimuli that confound sensitivity to change with attentional disengagement (see Discussion). Thus, in spite of the prominence of the attentional disengagement account of ASD, there is no clear answer to the basic question of whether disengagement deficits are present in children with ASD independently of global developmental delays. Here, we test this question using an unconstrained free-viewing paradigm, matching the conditions under which apparent disengagement deficits have been previously reported, but now testing high-functioning children with ASD and their age and IQ-matched typical children.

According to the social orienting hypothesis, a failure of individuals with autism to prioritize social information gives rise to the cognitive profile of ASD: given that it is from other people that we learn much of what we know, a failure to preferentially attend to social stimuli could lead to far-reaching cognitive deficits (Klin, Jones, Schultz, & Volkmar, 2003; Mundy & Rebecca Neal, 2000; Schultz, 2005). The social orienting hypothesis has wide appeal for its parsimony and anecdotal agreement with behaviors observed in autism, but evidence for the hypothesis is inconsistent. Some studies have reported that toddlers with ASD spend less time looking at faces than TD toddlers do (Chawarska & Shic, 2009), that toddlers (Chawarska, Volkmar, & Klin, 2010) and adolescents (Kikuchi, et al., 2011) with ASD are faster to disengage attention from a face, and that even when individuals with autism do look at faces, they show different patterns of eye fixation (Snow et al., 2011), focusing more on mouths than eyes relative to typical subjects (Jones, Carr, & Klin, 2008). Yet other studies report that children and young adults with ASD prioritize social stimuli to the same degree as TD participants when searching a scene (Fletcher-Watson, Leekam, Findlay, & Stanton, 2008; New et al., 2010; Sheth et al., 2011), and that infants who later develop ASD exhibit the same attentional capture by faces as their

\[1\] One study (Kawakubo et al., 2007) did report larger disengagement costs in ASD vs. TD subjects, but a similar deficit was found in IQ-matched mental retardation controls. The deficit likely derived from low IQ rather than autism.
typically developing counterparts, and even spend more time overall looking at faces than TD controls do (Elsabbagh et al., in press). Thus, it remains unclear whether social orienting is truly impaired in ASD, and whether social orienting impairments may have any role in the development of the signature characteristics of autism.

The goal of this study is to test two of the most parsimonious and widely-embraced accounts of the etiology of autism: attentional disengagement and social orienting. First, do children with ASD have “sticky” attention, independently of global developmental delay? Second, do children with ASD fail to prioritize social stimuli when orienting attention? To answer these two questions, we tested a large group of well-characterized children with ASD (N=44) and age- and IQ-matched typically developing children (N=40) in a free viewing paradigm.

Method

All experimental protocols were approved by the MIT Institutional Review Board.

Participants:

Our participant pool comprised 44 children with ASD and 40 typically developing (TD) controls, matched on both chronological age and non-verbal IQ, measured by the Kaufman Abbreviated Intelligence Test (KBIT-2; Kaufman & Kaufman, 2004). Control participants were drawn from an original pool of 70 total TD children tested on this task; this original TD pool had an above-average mean non-verbal IQ, necessitating the exclusion of those with the highest IQ to equate the mean IQ across groups. We kept all ASD participants and removed the smallest number of TD participants necessary to yield an IQ match (p > .1). In the resulting groups, mean ages were 9.2 years for ASD children (±1.7 SD) and 8.6 years (±2.1 SD) for TD children (no significant difference; p = .15; Cohen’s d = 0.32), and mean Performance IQ was 108.8 for ASD (±16.2 SD) and 113.6 (±13.2 SD) for TD (no significant difference; p = .14; d = -0.32). Neither age nor IQ was correlated with our attentional measures, indicating that excluding participants to make the mean age or IQ more similar across groups would not alter our findings (see Figure S1 in the Supplemental Material available online). Analyzing the original group of 70 TD children yielded results consistent with those we report here. Six (14%) of ASD subjects were female and six (15%) of TD subjects were female. The same pattern of results was observed in each gender when analyzed separately.

Children with ASD had a DSM-IV diagnosis from a trained clinician and met the criteria for ASD or Autistic Disorder on the Autism Diagnostic Observation Schedule administered by a research-reliable psychologist (ADOS; Lord et al., 2000; see Table S2 for a summary of ADOS scores). Children with autism were recruited through the Simons Foundation and the Boston Autism Consortium. Typically developing children were recruited from the local community. Potential participants were excluded if they had any history of birth or brain trauma, non-corrected visual impairments or a non-verbal IQ of less than 80. All participants had normal or corrected to normal vision. Participants received modest monetary compensation as well as small motivating prizes for their participation.

Stimuli & Task design:

Stimuli were presented on a 17 inch LCD monitor with a built-in eye tracking camera (Tobii T120 eyetracker; Tobii Technology, Stockholm, Sweden). Participants viewed the stimuli from a chin rest positioned 52 cm from the screen. We measured attentional disengagement and social orienting using the “gap-overlap” paradigm (Reulen, 1984a, 1984b; Reuter-Lorenz, Hughes, & Fendrich, 1991; Saslow, 1967). Figure 1 depicts the series of events in each trial: each
trial began with a 1 second presentation of a blank white screen, followed by the appearance of a color photograph of a face or object in the center of the screen (7°x7°). After a delay of 1 or 2 s, a peripheral color photograph appeared at 14° eccentricity, randomly to the left or right of fixation. Variability (1 or 2 s) in the peripheral stimulus onset time kept participants from anticipating exactly when it would appear and making anticipatory saccades. Children were instructed to simply “look at the pictures in whatever way you want to, but pay attention to the screen the whole time”. Each child completed two runs of 64 trials each, for a total of 64 shift trials and 64 disengage trials.

Figure 1. Series of events in each trial. In each trial, a stimulus appeared at the center of the screen first for one or two seconds, and then a second stimulus appeared at 14 deg. in the periphery. In “shift” trials, the central stimulus disappeared at the onset of the peripheral stimulus, so no “disengagement” was required. In “disengage” trials, the central stimulus remained onscreen for the entire trial duration, requiring participants to disengage attention from the central stimulus in order to move their eyes to the periphery. Both the central and peripheral stimuli were either social images (faces) or nonsocial images (fruits, vegetables, or trains), manipulated independently.

Four factors were manipulated orthogonally in a 2x2x2x2 design. First, each trial was either a “shift” trial or a “disengage” trial: in shift trials, the central stimulus disappeared at the onset time of the peripheral stimulus, allowing participants to freely shift attention to the periphery. In disengage trials, the central stimulus remained onscreen until the end of the trial; saccading to the peripheral stimulus necessitated disengaging attention from the central stimulus. Second, the central stimulus was either social (a face) or nonsocial (a fruit, vegetable, or train). Third, the peripheral stimulus was either social or nonsocial. Stimuli were never repeated; each child saw a total of 256 unique photographs over the course of the experiment.
We chose these stimulus categories to provide a broad sampling of the kinds of images that might elicit attentional differences between ASD and TD children. For example, vehicles may be of particular interest to some children with autism; the inclusion of trains provided a strong test of whether stimuli of interest could interfere with disengagement in children with ASD. Presenting unique images on every trial eliminated potential confounds stemming from stimulus repetition, for example by priming (Maljkovic & Nakayama, 1994). Finally, as noted earlier, the second stimulus appeared after the first stimulus had been displayed for either one second or two seconds. All trials were randomly interleaved within a run, but trials were presented in the same order for every participant to avoid any potential influence of differences in stimulus order across groups.

Eye tracking:
Gaze position was recorded at 120 Hz using a Tobii T120 eyetracker. Prior to the start of each run, participants competed a brief calibration procedure to ensure accurate tracking. Left- and right- eye gaze positions were recorded separately, but for subsequent analyses, to improve the quality of the data, the left- and right- eye positions were averaged to determine gaze position. Most studies of attentional disengagement in ASD have used less precise eye tracking measures, for example, electrooculography (EOG) or video recording. The use of an infrared eye tracking system in this study yielded richer data than in many previous studies, allowing us to examine not only when disengagement occurred, but also whether eye gaze patterns to individual stimuli differed between groups (see Figure S3).

Saccadic reaction time analysis:
To measure attentional disengagement cost, we measured saccadic reaction times (SRTs), defined as the time between the onset of the peripheral stimulus and the first eye gaze measurement that fell within the peripheral stimulus. We included only trials that met three quality criteria: 1) no more than 25% of eye gaze measurements were missing (not properly read from the eye tracker) in that trial 2) the child was looking at the central stimulus location during the last 250 ms prior to the peripheral stimulus onset, and 3) the child made an eye movement to the peripheral stimulus within 2s after its onset. The number of trials thrown out due to these quality criteria did not differ across groups (ASD: an average of 19.9% of trials per child ± 15.2% sd across participants, TD: 16.0% of trials ± 14.8%; p = .09; d = 0.26). If fewer than half of a participant’s trials were usable, the child was excluded from the analysis (47 ASD and 43 TD children were originally analyzed and three from each group were excluded based on these criteria). In the subjects retained for analysis, the number of discarded trials did not differ across conditions in our tests of disengagement or social orienting (F1,82 = 0.22; p = .64; ηp² = 0.003 for disengagement and F1,82 = 2.40; p = .13; ηp² = 0.028 for social orienting), and there was no group difference in the distribution of discarded trials across conditions (F1,82 = 0.076; p = .78; ηp² = 0.001 for the group x condition interaction in disengagement and F1,82 = 0.019; p = .89; ηp² < 0.001 for the group x condition interaction in social orienting). 45.5% of ASD children and 45.0% of TD children had at least one trial excluded from the analysis based on the third (long SRT) criterion (no group difference; p = .50; d = 0.059). Among participants who had one or more trials excluded because of long SRTs, the mean number of excluded trials was 1.45 in ASDs and 1.67 in TDs (no group difference; p = .27; d = .0.12).

Disengagement costs, i.e., the extra time that it took participants to orient to the peripheral stimulus when the central stimulus remained onscreen, were computed as the mean SRT from disengage trials minus the mean SRT from shift trials. Error bars on the mean SRTs
and disengagement costs were obtained through a bootstrapping analysis (Efron, 1981): on each of 5,000 iterations, the data were resampled with replacement across participants and the group statistic was recomputed; error bars show ±1 SD of the bootstrapped distribution. Similarly, significance tests were conducted using permutations tests (Pitman, 1937), which characterized the null distribution by randomly assigning the group labels on each of 5,000 iterations. We used this non-parametric significance test for our planned comparisons to avoid assuming normality of the SRT distribution in our sample. ANOVA analysis showed the same pattern of results. Effect sizes for tests of differences are reported as Cohen’s d and partial eta squared, and effect sizes for tests of association are reported as Pearson’s r.

Results

Saccadic reaction times

Our key dependent measure was saccadic reaction time (SRT): how long after the peripheral stimulus appeared did viewers take to bring their eyes onto that peripheral stimulus? We conducted a repeated measures ANOVA with SRT as the dependent measure; trial type (shift vs. disengage), central stimulus duration (1 or 2 s), central stimulus type (social vs. nonsocial), and peripheral stimulus type (social vs. nonsocial) as within-subject effects; and group (ASD vs. TD) as a between-subjects effect, along with all 1- to 5-way interactions. See Table S1 in the Supplemental Material for a breakdown of SRTs by condition. There were significant main effects of trial type (F1,82 = 198.10; disengage slower than shift; p < .0001; ηp² = .71) and central stimulus type (F1,82 = 32.22; shorter SRTs to social peripheral stimuli; p < .0001; ηp² = .28). The main effects of central stimulus duration (F1,82 = 3.56; p = .063; ηp² = .042), and group (F1,82 = 2.18; p = .14; ηp² = .026) were not significant. One interaction, disengagement trial type x peripheral stimulus type, was significant (F1,82 = 5.47; p = .022; ηp² = .063): participants showed smaller disengagement costs when a social stimulus appeared in the periphery. Crucially, there was no interaction of group with any factor (e.g.: group x trial type: F1,82 = 0.74; p = .39; ηp² = .009; group x central stimulus duration: F1,82 = 0.20; p = .65; ηp² = .002; group x central stimulus type: F1,82 = 0.004; p = .95; ηp² < .001; group x peripheral stimulus type: F1,82 = 0.067; p = .80; ηp² = .001). All higher-order interaction effects were not significant, ps > .05; ηp² < .05. Given the absence of significant group interactions, we proceeded with the planned comparisons to test for attentional disengagement and social orienting impairments in children with ASD.

Figure 2a shows SRTs and disengagement costs for trials in which both the central and peripheral stimuli were nonsocial images – within these trials we tested for a disengagement deficit in children with ASD independent of any influence of social stimulus content. Because the central stimulus duration did not interact with any other factor and was varied to make the peripheral stimulus timing unpredictable, we collapsed across the two durations. If children with ASD have impaired attentional disengagement, they should show a larger disengagement cost than TD children (Figure 2a). On the contrary, while each group independently showed significant disengagement costs (both p < 0.001; permutation tests; see Method; d = 1.06 for ASD and d = 1.10 for TD), the disengagement cost did not differ across groups (p = .52; d = 0.024). Whether the nonsocial stimuli were trains or fruits/vegetables had no effect on SRTs in either group (central stimulus – ASD: p = .47, d = 0.025; TD: p = .12, d = 0.25; peripheral stimulus – ASD: p = .36, d = 0.11; TD: p = .15, d = 0.23). Disengagement cost also did not differ across groups when trials with long SRTs were included in the analysis (no filtering by SRT; p = .74; d = 0.01 for the group difference), nor was there a group difference in disengagement cost when
other stimulus types appeared in the central or peripheral locations (p = .41, d = -0.009 for social → nonsocial; p = .31, d = -0.13 for nonsocial → social; p = .06, d = -0.30 for social → social).

**Figure 2.** Tests of attentional disengagement and social orienting. **a)** Disengagement costs. SRTs (when both central and peripheral stimuli were nonsocial) were computed as the time for the eyes to arrive at the peripheral stimulus after its onset. Red bars are SRTs for ASD children and blue bars are SRTs for TD children. Error bars are ± 1 SD of the bootstrapped distribution (see Method). Both groups showed a
significant disengagement cost (SRT\textsubscript{disengage} - SRT\textsubscript{shift}, shown at right; both \( p < 0.001 \); both \( d > 1 \)), but there was no difference in disengagement cost between groups (\( p = 0.52; d = 0.024 \)). b) Social orienting. We pooled trials according to whether the peripheral stimulus was a social image (dark grey bars) or a nonsocial image (light grey bars). Both groups arrived significantly faster on social stimuli (both \( p < 0.001 \); \( d = 0.54 \) for ASD and \( d = 0.73 \) for TD), and there was no group x stimulus type interaction (\( p = 0.41; d = -0.07 \)).

To test for a social orienting deficit in ASD, we asked whether participants were faster to execute a saccade to a social stimulus than a nonsocial stimulus, an effect reported previously in typical adults (Crouzet, Kirchner, & Thorpe, 2010). Comparing SRTs for trials in which the peripheral stimulus was a social vs. nonsocial image, we found that both groups were significantly faster to saccade to a social stimulus (Fig. 2b; both \( p < 0.001 \); \( d = 0.54 \) for ASD and \( d = 0.73 \) for TD). ASD and TD groups did not differ in the magnitude of faster orienting to social vs. nonsocial peripheral stimuli (no group x peripheral stimulus type interaction; \( p = 0.41; d = -0.07 \)). This prioritized orienting to social stimuli was also present in both groups when trials with long (>2s) SRTs were included in the analysis (\( p = 0.10; d = 0.23 \) for ASD, \( p = 0.16; d = 0.22 \) for TD; \( p = 0.63; d = 0.04 \) for the group x peripheral stimulus type interaction). Following their initial saccades to the peripheral stimuli, the ASD and TD groups did not differ in the total time spent looking at either social (\( p = 0.29; d = 0.15 \)) or nonsocial (\( p = 0.57; d = 0.024 \)) peripheral images. The social content of the central stimulus had no influence on SRTs in either group (ASD: \( p = 0.66, d = 0.17 \); TD: \( p = 0.70, d = 0.16 \)). Finally, an additional analysis showed that ASD and TD children did not differ in their eye fixation patterns on either social or nonsocial stimuli (Supplementary Material, Gaze pattern analysis).

Attentional disengagement and social orienting effects were not independent, as revealed by a significant interaction of these two factors in the omnibus ANOVA (\( p = 0.022; \eta_p^2 = 0.063 \)) reflecting reduced disengagement costs when a social rather than a nonsocial stimulus appeared in the periphery. Importantly, the magnitude of this effect did not differ across groups (no group x trial type x peripheral stimulus type interaction; \( p = 0.32; \eta_p^2 = 0.012 \)). There was no interaction between central stimulus content and disengagement (no trial type x central stimulus type interaction; \( p = 0.29; \eta_p^2 = 0.014 \)).

These findings collectively show a remarkable degree of similarity between children with ASD and TD children in both attentional disengagement and social orienting. Both groups had significant disengagement costs in all conditions and both showed prioritized orienting to social stimuli, demonstrating that our study has sufficient power to detect even small differences in saccadic reaction times, yet the magnitude of the effects was nearly identical across groups in every case. Further analyses showed that ASD and TD children did not differ in their fixation patterns on either social or nonsocial stimuli (see Figure S3 in the Supplemental Material), and that our results cannot be explained by group differences in language abilities (see Figure S2).

**Discussion**

The present study tested two key signatures of attentional function that have been widely implicated in autism: attentional disengagement and social orienting. Each of these putative impairments has been proposed to lie at the root of other core aspects of the cognitive phenotype of autism (e.g., restricted interests and deficits in social cognition). However, we find no evidence that high-functioning children with ASD suffer from impairments in either attentional disengagement or social orienting (as indexed by saccadic eye movements). Instead, we find both attentional signatures are present in children with ASD, and both are of very
similar magnitude to those found in age- and IQ-matched typical children. Children with ASD disengaged attention as quickly as TD children, and were significantly influenced by social stimulus content, showing the same increased speed to orient to social vs. nonsocial stimuli that TD children did. Our study used a relatively large number of participants, affording good statistical power to detect a difference between ASD and TD children if it existed. The effects we report are not simply null findings when comparing across groups; they are positive findings that are independently significant in each group individually, and that are virtually identical in magnitude across groups. Although deficits in attentional disengagement or social orienting may exist under different circumstances from those tested here, our data indicate that high-functioning children with ASD do not suffer from across-the-board impairments in either attentional disengagement or social orienting.

Our findings are consistent with some prior studies of disengagement in ASD, especially those that required a saccade to the peripheral stimulus (Kelly, et al., 2013). However, they are inconsistent with the majority of the studies that examined disengagement in a free viewing paradigm. How can the discrepancies between our results and prior free-viewing findings be reconciled? For attentional disengagement, the best-known prior report of a deficit in ASD (Landry & Bryson, 2004) found an attentional disengagement cost of about two seconds. This is more than an order of magnitude larger than the disengagement cost reported in other studies (Kawakubo, et al., 2007), and the disengagement costs we found here in children with ASD. One possibility is that the disengagement cost in Landry and Bryson’s study was overestimated because of the handful of trials where saccadic reaction times were seven to eight seconds - many times what would be expected for even very slow attentional disengagement. Later studies showed that very slow SRTs are associated with global developmental delay rather than with autism (Chawarska et al., 2010).

Elsabbagh et al. (Elsabbagh, et al., 2013; Elsabbagh, et al., 2009) reported slower disengagement in infant siblings of children with ASD, especially those who went on to develop autism themselves. Substantial design differences between their study and ours may account for the conflicting results. Elsabbagh et al. presented the same peripheral stimulus on every trial, which might have interacted with the speed of orienting, e.g. through repetition priming (Maljkovic & Nakayama, 1994). They also used animated cartoons as the central stimuli that switched to static images at the time of the peripheral stimulus onset; this change in motion was likely a salient attentional cue itself, and may well have interacted with disengagement. Finally, global developmental delay (as reflected by lower Mullen scores in the infants who later developed autism) may contribute to disengagement deficits. In another study of adults performing a gap-overlap task, Kawakubo et al. (Kawakubo, et al., 2007) found that observers with ASD were slower to disengage attention than TD controls in the overlap condition. However, their participants with ASD had very low IQ (~40). In fact, an IQ-matched mental retardation group showed similar disengagement delay as the autism group. Thus, although our results run counter to the prevailing belief that attentional disengagement is impaired in autism, this was the first rigorous test of this hypothesis in a large sample of IQ-matched children using a free viewing paradigm.

With regard to social orienting, Chawarska et al. (2010) reported that toddlers with ASD had shorter saccadic reaction times when shifting attention away from social stimuli than did TD toddlers, but not when shifting attention away from nonsocial stimuli. Though their study did not measure disengagement costs directly, their results are suggestive of smaller social disengagement costs for toddlers with ASD. However, Chawarska et al. presented only 10 nonsocial trials, all blocked together at the beginning of the study before the 64 social trials, confounding the social vs. nonsocial manipulation with participants’ time spent performing the
task. Any trend in reaction times over the course of the experiment would have differentially affected social and nonsocial trials in their study, so it is not clear whether the larger social disengagement costs Chawarska et al. report are truly due to social orienting.

Thus, prior findings are not inconsistent with our conclusion that children with autism do not have across-the-board impairments in attentional disengagement or social orienting. On the other hand, these deficits may exist in circumscribed situations or subject groups not tested here. For example, it is possible (if unparsimonious) that attentional deficits exist in very young children but quickly disappear. Indeed, the severity of some symptoms in autism tends to decrease with age (Elsabbagh & Johnson, 2007). Yet in separate analyses of our data on the younger half of our participants (ages 5-9 years), we still find no evidence for impairments in either attentional disengagement or social orienting, and neither disengagement nor social orienting was correlated with age in either group in our participant pool (see Figure S1 in the Supplemental Material available online). Nonetheless, it will be important in future to test whether ASD children younger than those tested here have an attentional impairment (while un-confounding autism from global developmental delay, ideally by testing children with normal cognitive abilities). Even so, autism is a lifelong disorder, and the defining characteristics of ASD should persist to some degree across development and interventions. That we find no disengagement or social orienting deficits in school-aged children with ASD substantially weakens the purported link between these abilities and autism.

Second, deficits in attentional disengagement and/or social orienting may emerge under real-world conditions, even if they are not apparent in more constrained laboratory tests. The findings of Dawson et al. (Dawson et al., 2004), for example, point toward this possibility. In their experiment, conducted during face-to-face interaction with children with ASD, social and nonsocial auditory stimuli (e.g., humming and snapping fingers vs. a phone ringing or blowing a whistle) were produced by one experimenter while another experimenter was interacting with the child. Children with ASD were less likely than TD children to orient toward social sounds, an effect that was significantly reduced for nonsocial sounds. Similarly, studies using movies of naturalistic social situations as stimuli, perhaps a halfway point toward real-life interactions, have produced atypical eye gaze patterns in ASD, although these findings are not without challenges (Chawarska, Macari, & Shic, in press; Jones, et al., 2008; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Norbury et al., 2009; Rice, Moriuchi, Jones, & Klin, 2012; Speer, Cook, McMahon, & Clark, 2007). For all these reasons, it will be worthwhile to study attentional function in ASD in more naturalistic, real-world contexts.

Our results show that the core attentional functions of disengagement and social orienting are intact in ASD. Together with other recent studies (Grubb et al., 2013; Jiang, Capistrano, Esler, & Swallow, 2013; K. Koldewyn, Jiang, Weigelt, & Kanwisher, 2013; Kami Koldewyn, Weigelt, Kanwisher, & Jiang, 2012), these findings challenge the once-popular idea that deficits in attentional function may be the root cause of autism. Instead, these data are more consistent with the idea that domain-specific deficits in social cognition are the crux of the matter in autism. In its strongest form this hypothesis holds that social deficits appear first in development in autism, and play a causal role in the etiology of the rest of the autism phenotype. Further research in two key veins will be necessary to examine this possibility. First, because attention includes a variety of functions, it is important to test whether other core aspects of attention, particularly those involved in planning and other central executive functions, are also intact in ASD during early development. Such tests should control for co-morbid conditions such as intellectual delay, ADHD, and reduced inner speech. Second, future research should examine how a primarily domain-specific disorder could produce broad deficits in behavior, including some that may resemble attention deficits in everyday function.
Atypical social functioning may modulate attentional priority in the real world even in people whose core attentional functions (e.g., disengagement, endogenous cueing) are intact. Further, early social deficits may change the way the brain learns and develops, producing an array of later deficits in nonsocial domains. Indeed, understanding the causal trajectory that leads to autism within the first three years of life remains the most fundamental question in autism research, and the most important if we are ever to intervene effectively to alter that developmental trajectory.

Author Contributions
The study was designed by Y.V.J., K.K., and N.K. Testing and data collection were performed by K.K. and J.F. Data analysis and interpretation were performed by J.F. and K.K. under the supervision of Y.V.J. and N.K. The paper was written by J.F., K.K., Y.V.J., and N.K.

Acknowledgments
The authors would especially like to thank all the participants and their families for their time and contribution to our research. We are grateful to all of the families at the participating SFARI Simplex Collection (SSC) sites, as well as the principal investigators (A. Beaudet, R. Bernier, J. Constantino, E. Cook, E. Fombonne, D. Geschwind, E. Hanson, D. Grice, A. Klin, R. Kochel, D. Ledbetter, C. Lord, C. Martin, D. Martin, R. Maxim, J. Miles, O. Ousley, K. Pelphrey, B. Peterson, J. Piggot, C. Saulnier, M. State, W. Stone, J. Sutcliffe, C. Walsh, Z. Warren, E. Wijsman). We are also grateful to all of the families participating in the Autism Consortium collection, as well as the principal investigators. We thank Sarah Weigelt, Alex Kell, and Josh Julian for assistance with data collection.

Funding
This study was supported by funds from the Ellison Medical Foundation awarded to NK, by a grant from the Simons Foundation to the Simons Center for the Social Brain at MIT, and by Eunice Kennedy Shriver National Institute Of Child Health and Human Development Award F32-HD075427 to JF.

References


**Supplemental Material**

*Age and IQ*

ASD and TD groups were matched on both age and non-verbal IQ (mean ages were 9.2 ±1.7 years for ASD and 8.6 ± 2.1 years for TD; group difference: p = .15, d = 0.32; mean PIQs were 108.8 ± 16.2 for ASD and 113.6 ± 13.2 for TD; group difference: p = .14, d = -0.32). Since our participant pool comprised high-functioning children with no global developmental delay, IQ would not be expected to correlate with our attentional measures. Nonetheless, to make sure even the small and nonsignificant differences in age and IQ could not account for our findings, we tested whether attentional disengagement or social orienting was correlated with age or IQ in our participant pool. The plots in Figure S1 show that there was no significant correlation between either attentional measure and age or IQ in either group. The lack of a relationship between attentional disengagement/social orienting and age or IQ in our sample implies that excluding additional children to make the mean age or IQ more similar across groups would not alter the relative magnitude of our attentional measures between groups. These data, along with the fact that our results hold when analyzed separately in the younger and older halves of our participant pool (5-8 and 9-12 year-olds), give no indication that disengagement or social orienting deficits would appear in younger or older groups than the one tested here. Nonetheless, it will be important in the future to test for attentional changes in children under the age of 5.
Figure S1. Correlation of age and IQ with measures of attentional disengagement and social orienting. Red data = ASD; blue data = TD. Disengagement costs (upper plots) are $\text{SRT}_{\text{disengage}} - \text{SRT}_{\text{shift}}$ from nonsocial→nonsocial trials. Peripheral social advantage (lower plots) is the additional time it took to saccade to a nonsocial stimulus vs. a social stimulus in periphery. Regression lines show least squares linear fits to the data. None of the correlations between age/IQ and disengagement/social orienting was significant in either group.

Language ability

Language ability was assessed with two measures: the Peabody Picture Vocabulary Test (PPVT-IV), which assesses vocabulary skills by asking participants to choose a picture that best corresponds to a word read aloud by the experimenter, and the Test for Reception of Grammar (TROG-2), which uses a similar format to assess grammar skills. TD children scored significantly higher than ASD children on both language measures (mean PPVT score was 109.9 ± 19.4 for ASD and 128.1 ± 14.1 for TD; group difference: p < .001, d = -1.07; mean TROG score was 96.3 ± 19.6 for ASD and 110.8 ± 11.7 for TD; group difference: p < .001, d = -0.89), consistent with prior reports of language difficulties in ASD (Charman et al.; Scarborough, Rescorla, Tager-Flusberg, Fowler, & Sudhalter, 1991). We tested whether language scores were correlated with either attentional disengagement or social orienting abilities in our participants. Figure S2 shows that neither group showed a significant correlation between the attentional measures and language scores. Thus, the superior language abilities of our TD participants cannot explain any difference (or lack thereof) in attentional disengagement or social orienting between groups.
Figure S2. Correlation of language ability with measures of attentional disengagement and social orienting. Red data = ASD; blue data = TD. Disengagement costs (upper plots) are $SRT_{\text{disengage}} - SRT_{\text{shift}}$ from nonsocial→nonsocial trials. Peripheral social advantage (lower plots) is the additional time it took to saccade to a nonsocial stimulus vs. a social stimulus in periphery. Regression lines show least squares linear fits to the data. None of the correlations between age/IQ and either language measure was significant in either group.

**Gaze pattern analysis**

Once their eyes arrive at a given stimulus, did children from the ASD and TD groups differ in their fixation patterns on that stimulus? To address this question, we performed a multivariate pattern classification analysis to attempt to distinguish the groups on the basis of their gaze patterns. The groups may have differed in their fixation patterns on the central stimulus, the peripheral stimulus, or both, so we collected eye gaze measurements from three time windows: during the central stimulus presentation (first 1s), during the first 500 ms of the peripheral stimulus presentation (to capture the initial 1-2 fixations participants made on the peripheral stimulus), and during the entire 3s peripheral stimulus presentation. To construct the gaze pattern for a given trial and time window, we began with a blank (white) 200x200 pixel image positioned at the location of the stimulus that was onscreen during that epoch. For every gaze measurement collected during that time window, we added a black dot to the image at the $(x,y)$ location of the gaze measurement. The resulting image was a visualization of the locations where the child looked during that time window on that trial. These binary gaze pattern images served as training and test vectors in the pattern classification analysis. Gaze patterns were collected separately for each trial and each time window, resulting in 384 (128 trials x 3 time windows) patterns of eye position measurements per child. We performed the classification analysis separately within each trial and each time window, meaning that classification was performed separately for each of the 256 images that participants saw in the experiment. We trained a support vector machine (SVM) pattern classifier with a linear kernel (LIBSVM library;
Lin & Chang, 2011) to distinguish the eye gaze data from the two groups to a given image. We repeated each classification 1000 times in a cross-validation procedure in which the classifier was trained on ~80% of the participants and tested on the remaining 20%. To test the significance of the classification, we compared the overall classifier performance, pooled across all trials, with a permuted null distribution, obtained by repeating the above analyses 5000 times and shuffling the group labels on each iteration, removing the information that the SVM classifier was attempting to discover.

Figure S3a shows classification performed separately within each of the three time windows: in each case, classification was at chance level in distinguishing the viewing patterns of ASDs versus TDs (green bars; central stimulus: p = .48, d = 0.09; first 500 ms of peripheral stimulus: p = .64, d = -0.17; full peripheral stimulus duration: p = .50, d = 0.03). Classification was also at chance in all three epochs for both social and nonsocial stimuli when considered separately (all p ≥ .34; all d ≤ 0.41).

To verify that the chance classification above was indicative of similar viewing patterns across groups rather than a lack of power, we repeated the classification using the same eye gaze patterns, this time classifying the fixation patterns made to different stimuli within each group separately. Classification was performed on pairs of stimuli; for example, the classifier was trained to distinguish eye gaze patterns corresponding to stimulus X and stimulus Y, within the ASD group. This gave a measure of whether gaze patterns were reliably similar across participants for the same image, but reliably different across different images. Classification was performed for all possible trial pairings, and for each pairing, the classifier was trained on ~80% of participants and tested on the remaining 20% 1000 times in a cross-validation procedure as before. This within-group classification was significantly above chance for each group in all three time windows (Fig. S3a red and blue data; all p < .001; all d > 5). As a final test of whether ASD and TD children looked at the same locations within the stimuli, we trained the classifier to distinguish the eye gaze data from pairs of trials within each group as described above, and then tested classification performance on data from the other group (i.e., we trained on data from ASDs and tested on data from TDs, and vice versa). In all three time windows, classification in this cross-group validation was significantly above chance and similar in magnitude to the within-group classification (73.0% correct for the central stimulus, 59.1% for the first 500ms of the peripheral stimulus, and 65.1% for the full peripheral stimulus duration; all p < .001; all d > 5). Thus, children within each group made consistent patterns of fixations with each other that were reliably different across different stimuli, but indistinguishable across groups.

We performed the classification on pairs of stimuli; it is possible that classification was better when discriminating stimuli of different categories than when discriminating stimuli of the same category. We examined classification performance for the three types of stimulus pairings (social paired with nonsocial; nonsocial paired with nonsocial; and social paired with social) independently. Figure S3b shows classification performance during the central time window for individual stimulus pairings, broken down by the type of stimuli that were paired. Each point is one stimulus pairing; performance in classifying that pair in TD children is plotted on the x axis, and performance in ASD children is plotted on the y axis. In each case, performance was significantly correlated across groups – a pair of stimuli that was difficult to discriminate based on gaze patterns in TD children was also difficult to discriminate in ASD children, and likewise pairs that were easily classified in TD children were generally easily
classified in ASD children as well. Mean classifier performance was comparable across the three types of stimulus pairings: the far right plot in Figure S3b shows the mean performance for each of the three pairing types. The difference among the means, evaluated with a permutation test, was not significant in either group (the means also did not differ in data from the peripheral or early peripheral time windows). Thus, it is reasonable to collapse across all stimulus pairings when evaluating the overall classification performance reported in Figure S3a.

Figure S3. Classification of eye gaze patterns. a) We performed a multivariate pattern classification analysis on participants’ collected eye positions from three time windows: 1) the first 1s of each trial, during the central stimulus 2) the first 500 ms of the peripheral stimulus, and 3) the entire 3s presentation of the peripheral stimulus. In each case, the two groups could not be distinguished by any reliable differences in their fixations (green bars), but nonetheless showed consistent gaze patterns that could be distinguished across trials within each group (red bars).
hatched bars are ASDs, blue bars are TDs). The shaded region shows the classification accuracy that would be expected by chance, determined by a permutation analysis. b) Classification performance for individual stimulus pairings, shown separately for the three different types of pairings. In each case, performance across pairs was significantly correlated between the ASD and TD groups – a given stimulus pairing was similarly difficult to classify in the two groups. Mean classification performance for the three pairing types is shown in the far right plot (error bars are one standard deviation of the mean). The difference among the means, evaluated with a permutation test, was not significant in either group (p = .11, d = 0.08 for ASD; p = .10, d = 0.08 for TD).

We used this multivariate pattern classification analysis in order to compare the distributed patterns of fixations across groups. Children may have oriented with the same speed and spent comparable amounts of time exploring the stimuli, but still differed in where they looked within the stimuli, for example avoiding the eyes in a face or focusing just on a single feature of an object. Our classification analysis had the power to detect such differences in the locations of participants’ fixations, and thus complemented the SRT analysis, which focused on saccade timing.

A number of studies have shown atypical looking patterns to faces and other social stimuli in ASD (Dalton et al., 2005; Jones, Carr, & Klin, 2008; Pelphrey et al., 2002; Snow et al., 2011); in contrast, we found no difference in fixation patterns on social or nonsocial stimuli between ASD and TD children. Prior studies have typically tracked looking behavior over extended durations with complex social situations and/or asked participants to extract social information from the stimuli. Under these conditions, looking behavior may well be different between groups and may reflect the core social impairments in ASD. Our goal here was different: we presented short duration stimuli in the absence of a social task to test whether social images capture attention differently for ASD and TD children. Some studies have taken a similar approach: using a free viewing task with short duration stimuli, Pelphrey et al. (Pelphrey, et al., 2002) found that adults with ASD devoted less time to looking at the core features of faces than TD controls. However, their study included just five participants with autism, and the ASD and control groups were not matched on IQ. IQ differences in particular could underlie the differences in scanning behavior they observed. Fletcher-Watson et al. (Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009) found that when presented with social and nonsocial scenes simultaneously, adults with ASD less frequently made their first fixations to the social scenes than TD controls. Nevertheless, their ASD and TD groups both showed a strong bias toward looking at social images over nonsocial images on the first fixation, indicating some degree of intact social orienting in ASD adults. Thus, while children with ASD may look differently at faces than TD children during social interactions or prolonged exploration of a socially-rich environment, our data show that in the absence of social demands and on a relatively fast timescale, ASD and TD children look at the same locations in both social and nonsocial images.
Table S1. Mean SRTs in milliseconds ± 1 sd across participants for each experimental condition. “Non” refers to a nonsocial stimulus and “Soc” refers to a social stimulus; “Non→Soc”, for example, denotes trials in which the central stimulus was a nonsocial image and the peripheral stimulus was a social image.

<table>
<thead>
<tr>
<th></th>
<th>central stim duration</th>
<th>Shift trials</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 s</td>
<td>Non → Non</td>
<td>262.3 ± 48.5</td>
<td>259.2 ± 50.4</td>
<td>259.3 ± 57.8</td>
<td>251.0 ± 34.2</td>
</tr>
<tr>
<td></td>
<td>2 s</td>
<td></td>
<td>262.9 ± 42.4</td>
<td>241.8 ± 36.1</td>
<td>260.3 ± 62.5</td>
<td>256.4 ± 41.5</td>
</tr>
<tr>
<td>ASD</td>
<td>1 s</td>
<td>Non → Soc</td>
<td>262.4 ± 36.1</td>
<td>279.4 ± 55.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 s</td>
<td></td>
<td>272.8 ± 54.0</td>
<td>266.7 ± 45.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TD</td>
<td>1 s</td>
<td>Soc → Non</td>
<td>327.7 ± 77.4</td>
<td>313.7 ± 87.9</td>
<td>301.5 ± 57.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 s</td>
<td></td>
<td>310.2 ± 81.9</td>
<td>273.9 ± 60.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 s</td>
<td>Soc → Soc</td>
<td>325.2 ± 66.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 s</td>
<td></td>
<td>319.8 ± 57.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Disengage trials

<table>
<thead>
<tr>
<th></th>
<th>Non → Non</th>
<th>Non → Soc</th>
<th>Soc → Non</th>
<th>Soc → Soc</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD</td>
<td>1 s</td>
<td>327.7 ± 77.4</td>
<td>294.6 ± 62.3</td>
<td>307.2 ± 81.4</td>
</tr>
<tr>
<td></td>
<td>2 s</td>
<td>310.2 ± 81.9</td>
<td>295.2 ± 78.7</td>
<td>313.7 ± 87.9</td>
</tr>
<tr>
<td>TD</td>
<td>1 s</td>
<td>330.4 ± 56.9</td>
<td>325.2 ± 66.1</td>
<td>323.1 ± 61.4</td>
</tr>
<tr>
<td></td>
<td>2 s</td>
<td>319.8 ± 57.4</td>
<td>295.0 ± 64.5</td>
<td>330.1 ± 65.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>measure</th>
<th>ASD (n = 44; 14% female)</th>
<th>TD (n = 40; 15% female)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ (K-bit)</td>
<td>108.8 ± 16.2 80-139</td>
<td>113.6 ± 13.2 91-139</td>
<td>0.15</td>
</tr>
<tr>
<td>age (years)</td>
<td>9.2 ± 1.7 5.8-12.9</td>
<td>8.6 ± 2.1 5.4-12.6</td>
<td>0.14</td>
</tr>
<tr>
<td>vocabulary (PPVT)</td>
<td>109.9 ± 19.4 81-160</td>
<td>128.1 ± 14.1 105-160</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>grammar (TROG)</td>
<td>96.3 ± 19.6 58-134</td>
<td>110.8 ± 11.7 74-137</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>SRS</td>
<td>77.1 ± 10.8 36-90</td>
<td>45.0 ± 8.3 34-72</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ADOS (CSS)</td>
<td>7.1 ± 1.8 4-10</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table S2. Participant demographics. Non-verbal IQ was assessed using the Kaufman Abbreviated Intelligence Test (KBIT-2; Kaufman & Kaufman, 2004). Vocabulary skills were assessed using the Peabody Picture Vocabulary Test (PPVT-IV; Pearson Education, Inc., San Antonio, TX), based on scores from 36 ASD and 33 TD children (the remaining children did not complete the vocabulary assessment). Grammar skills were assessed using the Test for Reception of Grammar (TROG-2; Pearson Education, Inc., San Antonio, TX), based on scores from 36 ASD and 33 TD children. SRS is the Social Responsiveness Scale, Second Edition (Western Psychological Services, Torrance, CA), based on scores from 37 ASD and 26 TD children. Autism severity was assessed using the calibrated severity score (CSS) from the Autism Diagnostic Observation Schedule administered by a research-reliable psychologist (ADOS; Lord et al., 2000). p values were determined by a permutation test on the group mean difference.

Supplemental References


