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RESEARCH ARTICLE

Deficits in Adults With Autism Spectrum Disorders When Processing Multiple Objects in Dynamic Scenes

Kirsten O'Hearn, Laura Lakusta, Elizabeth Schroer, Nancy Minshew, and Beatriz Luna

People with autism spectrum disorders (ASD) process visual information in a manner that is distinct from typically developing individuals. They may be less sensitive to people's goals and, more generally, focus on visual details instead of the entire scene. To examine these differences, people with and without ASD were asked to detect changes in dynamic scenes with multiple elements. Participants viewed a brief video of a person or an inanimate object (the "figure") moving from one object to another; after a delay, they reported whether a second video was the same or different. Possible changes included the figure, the object the figure was moving from, or the object the figure was moving toward (the "goal"). We hypothesized that individuals with ASD would be less sensitive to changes in scenes with people, particularly elements that might be the person's goal. Alternately, people with ASD might attend to fewer elements regardless of whether the scene included a person. Our results indicate that, like controls, people with ASD noticed a change in the "goal" object at the end of a person's movement more often than the object at the start. However, the group with ASD did not undergo the developmental improvement that was evident typically when detecting changes in both the start and end objects. This atypical development led to deficits in adults with ASD that were not specific to scenes with people or to "goals." Improvements in visual processing that underlie mature representation of scenes may not occur in ASD, suggesting that late developing brain processes are affected. ***Autism Res*** *2011, 4: 132–142*. © 2011 International Society for Autism Research, Wiley Periodicals, Inc.

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As people interact with the environment, they visually process an array of distinct objects. To behave effectively, they must recognize these objects and understand their relationship to each other and the surroundings. The ability to attend to all the important (i.e., meaningful) aspects of a visual scene, and understand their significance, requires complex visual processing that may differ in neurodevelopmental disorders such as autism spectrum disorders (ASD). Individuals with ASD have a unique pattern of visual processing. They tend to focus on individual elements, possibly undermining their ability to process global configuration [Behrmann et al., 2006; Brosnan, Scott, Fox, & Pye, 2004; Dakin & Frith, 2005; Jemel, Mottron, & Dawson, 2006; Scherf, Luna, Kimchi, Minshew, & Behrmann, 2008]. Several theories have attempted to characterize this tendency, including Weak Central Coherence (WCC) [Frith & Happe, 1994; Happe, 1999] and Enhanced Perceptual Functioning [Mottron, Dawson, Soulieres, Hubert, & Burack, 2006]. Both theories highlight a local bias in visual processing, leading to superior performance on some tasks [i.e., embedded figures task, visual search; O'Riordan & Plaisted, 2001; Shah & Frith, 1983]. WCC integrates the local bias with a deficit in processing global configuration in ASD, potentially contributing to deficits on important visual tasks, such as face processing [Behrmann et al., 2006; Deruelle, Rondan, Salle-Collemiche, Bastard-Rosset, & Da Fonseca, 2008; Jemel et al., 2006]. WCC predicts that there would be limitations when visually processing complex scenes and objects in ASD, and these differences are sometimes evident [Jolliffe & Baron-Cohen, 2001; Nakahachi et al., 2008].

Data from change detection paradigms also indicate that there are differences in how individuals with ASD "see" complex naturalistic scenes. Change detection paradigms can assess sensitivity to different elements within a scene; changes to more "central" or "meaningful" elements may be detected faster or more accurately than other changes [Rensink, 2002; Ro, Russell, & Lavie, 2001]. A limitation of change detection paradigms is that it is difficult to identify at what level of processing a change is detected (e.g., percept, attended information, or matching). However, Rensink and colleagues argue that focused attention may be the dominant factor, and is necessary (though not sufficient) to detect a change [Rensink, 2002; Simons & Rensink, 2005]. These investigators also discuss the importance of attentional management—in other words, using attention in a way that is sensitive to the task at hand

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and utilizes high-level knowledge (including semantic knowledge and the overall visual layout of the scene). There is some evidence that such processes differ in ASD. Adults with ASD were impaired at detecting changes in objects that were semantically marginal in the scene, but not those that were central, compared to typical adults [Fletcher-Watson, Leekam, Turner, & Moxon, 2006]. Adults with ASD were also less likely to detect changes to objects that were "out of place" in a scene [e.g., a briefcase changing to a toaster in an office; Loth, Gómez, & Happé, 2008]. These findings suggest that the focus on individual element(s) in ASD may affect their ability to integrate elements together into a coherent representation of a complex scene. In contrast, a study of adolescents with ASD indicated that they were more sensitive to changes than typically developing individuals, presumably due to their strong visual search abilities [Smith & Milne, 2009].

This evidence suggests that there are differences in how individuals with and without ASD view *all* complex scenes, including those without people. However, another view suggests that these differences would be more evident in scenes with people, reflecting impairments in interpreting people's behavior and intentions/goals, and possibly contributing to the social deficits that are a core feature of ASD [Sasson, 2006]. A person's intention or goal is often evident from their direction of movement and gaze—people generally move toward and look at their goals. Individuals with ASD are sensitive to gaze direction [Falck-Ytter, 2010; Fletcher-Watson, Leekam, Findlay, & Stanton, 2008; Freeth, Ropar, Chapman, & Mitchell, 2010; Rutherford & Krysko, 2008], but there are subtle differences in this ability [de Jong, van Engeland, & Kemner, 2008; Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2008; Freeth, Chapman, Ropar, & Mitchell, 2010; Wallace, Coleman, Pascalis, & Bailey, 2006], along with distinct patterns of brain function in ASD [Dichter & Belger, 2007; Pelphrey, Morris, & McCarthy, 2005]. For instance, recent work indicates that, while adults with ASD looked at the people in scenes as much as controls, they were less likely to look at what that person was gazing at—the likely goal of that person's thoughts or actions [Fletcher-Watson, Leekam, Benson et al., 2008; Freeth, Chapman et al., 2010]. These differences in interpreting gaze may contribute to the joint attention deficits in ASD [Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997; Leekam, Lopez, & Moore, 2000; Mundy, Sigman, Ungerer, & Sherman, 1986]. Finally, individuals with ASD may be less likely to interpret some actions as intentional [Campbell et al., 2006; Castelli, Frith, Happe, & Frith, 2002; Rutherford, Pennington, & Rogers, 2006; for reviews, see Pelphrey, Adolphs, & Morris, 2004; Tuchman, 2003]. So, while people with ASD are generally more able to process mental state information than originally hypothesized [Perner & Leekam, 2008; Tager-Flusberg & Sullivan, 1994], a lack of sensitivity to gaze and other social information may lead to decreased attention to people's intentions and their goals.

Therefore, an important question is whether limitations in interpreting scenes in ASD reflect a lack of sensitivity to people and their behavior/goals, or the general visual pattern of a greater focus on individual elements than on global configuration. This general visual pattern could also undermine comprehension of complex social scenes, for instance by decreasing sensitivity to the relationships between elements (e.g., people and their goals). To examine these possibilities, the current study investigated whether individuals in ASD were less sensitive to changes in scenes with people, or whether the pattern of performance in ASD was similar in scenes with and without people. The former result would be consistent with theories positing that visual differences in ASD mainly reflect difficulties in interpreting human behavior; the latter would support theories positing that more general visual differences in ASD affect the ability to interpret visual stimuli including people. The task focused on specific aspects of visual processing thought to be affected in ASD, including the use of movement and gaze to highlight potentially important elements (i.e., goals), and attention to non-central (i.e., marginal) components of a scene. A change detection task with dynamic video clips was used. Dynamic videos were chosen because (1) previous work has shown striking inability to detect changes in video clips typically [Simons, Franconeri, & Reimer, 2000; Simons & Rensink, 2005], (2) differences in ASD in eye movements may be particularly evident in dynamic scenes [Speer, Cook, McMahon, & Clark, 2007], and (3) dynamic scenes are more naturalistic and allow movement cues to goals. Based on evidence that ASD affects sensitivity to goals [as suggested by eye gaze; Fletcher-Watson, Leekam, Benson et al., 2008; Freeth, Chapman et al., 2010; Pierno, Mari, Glover, Georgiou, & Castiello, 2006], we predicted that group differences would be more notable in the scenes that involved people than those without. In particular, we thought that the group with ASD would be less likely to detect changes in the object being gazed at. However, if the differences in ASD on this task reflect more general visual tendencies, group differences would be similar across conditions.

Methods

Participants

Participants included 37 people with ASD and 37 typically developing people matched individually to the participants with ASD on age (1.5 years for children, 3 years for adults) and IQ (15 points; see Table 1). Individuals with ASD were recruited through the University of Pittsburgh Autism Center of Excellence (ACE) Subject Core (HD# 055748)

Table 1. Demographics

	Children				Adolescents				Adults			
	ASD		Control		ASD		Control		ASD		Control	
Variable	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
n	8		8		15		15		14		14	
Age	11	1.07	11.13	0.835	15.2	1.7	15.07	1.83	22.14	4.15	22	4.51
Full scale IQ	100.25	6.69	105.63	9.74	105.87	13.15	106.07	7.44	105.86	12.05	105.43	10.63
Verbal IQ	104.25	13.25	104.5	9.26	104.87	12.28	105.33	8.47	105	10.14	103.5	10.35
Performance IQ	96	6.21	105.38	10.72	105.07	14.45	106.2	7.87	105.29	13.73	105.93	11.47
ADOS social	9.63	1.6			9.13	2.1			9	2.25		
ADOS comm	4.75	1.58			4.6	0.99			5.07	1.21		
ADOS total	14.38	2.88			13.73	2.43			14.07	3.17		

and were originally identified via announcements at parent meetings and autism group newsletters. Participants were diagnosed with ASD using the structured research diagnostic instruments, namely the Autism Diagnostic Interview [ADI; Lord, Rutter, & Couteur, 1994] and Autism Diagnostic Observation Schedule-G [ADOS; Lord, Rutter, & Goode, 1989], with the DSM-IV scoring algorithm [American Psychiatric Association, 2000]. Individuals with PDD-NOS were excluded, as were those with full-scale IQs <80 on the Wechsler Abbreviated Scale of Intelligence [WASI; Wechsler, 1999]. The diagnosis was also confirmed by expert assessment using the established clinical description of high-functioning autism [Minshew, 1996]. There was no known basis, for instance a genetic or infectious etiology, for the disorder. Typically developing participants were recruited through the ACE Subject Core and other ongoing projects in the laboratory. Participants were generally healthy, and had no history of head trauma, birth complications, seizures, or psychiatric disorders. Informed consent and assent was obtained from all participants or their legal guardians prior to the study, which was approved by the Institutional Review Board at the University of Pittsburgh.

Both children and adults with ASD were tested. While little is known about how visual processing of dynamic scenes develops, recent work suggests that change detection improves with age typically [Fletcher-Watson, Collis, Findlay, & Leekam, 2009; Shore, Burack, Miller, Joseph, & Enns, 2006]. Developmental changes may differ in ASD; Burack et al. found that while performance was comparable across groups, detection became more rapid and accurate with developmental level (as measured by a matrices task) in the typical children but not in those with ASD [Burack et al., 2009]. Thus, age (children/adolescents, adults) was included as a between-subjects factor in the initial omnibus analysis of variance (ANOVA).

Stimuli

Stimuli were short video clips with a person or an object moving from one object (the Start object) to another (the End object; Fig. 1). There were three conditions (Look forward, Look back, and Physical). The stimuli in the Look forward and Look back conditions were scenes with people while the Physical condition included only inanimate objects. The comparison of Look forward and Look back allowed us to examine whether participants used the direction of eye gaze to highlight "goal" objects, and how information about the Figure's gaze interacted with information from the Figure's movement. The order of conditions was counterbalanced, and the counterbalanced conditions were matched across groups.

Look forward condition. Participants were shown 37 videotaped motion events where the Figure (a person) moved from the Start object to the End object (the "goal"). The Figure looked at the End object that they were moving toward, making it likely that the End object was construed as the goal of the movement. All components in the event remained on the screen throughout the event. The Start and End objects were real objects, such as a table or chair. Left–right location of the Start and End objects were counterbalanced over events, as was the direction that the actor moved. After the delay, participants saw a second video event that "matched" the initial video in all or most ways. The matched event was either the same video as in the target event (No change; $N=9$); or had a different Start object ($N=9$), a different End object ($N=9$), or a different Figure ($N=5$). On some trials ($N=5$), there was a change in motion (such as jumping or hopping); these filler trials were included to increase the difficulty of the task and to avoid participants adopting a strategy of attending only to the Figure, and the Start and End objects. Changes in the Start and End objects were equated, in that the same set of changes (e.g., a TV to a cart) was used for both cases. This manipulation allowed us to examine the hypothesis that noticing changes in the End object, presumably the person's goal, would be more difficult for those with ASD.

Look back condition. These videos used the same background, objects, and Figures as the Look forward condition except that, while the Figure was still moving from the Start object to the End object, they were looking back at the Start object instead of looking forward to the

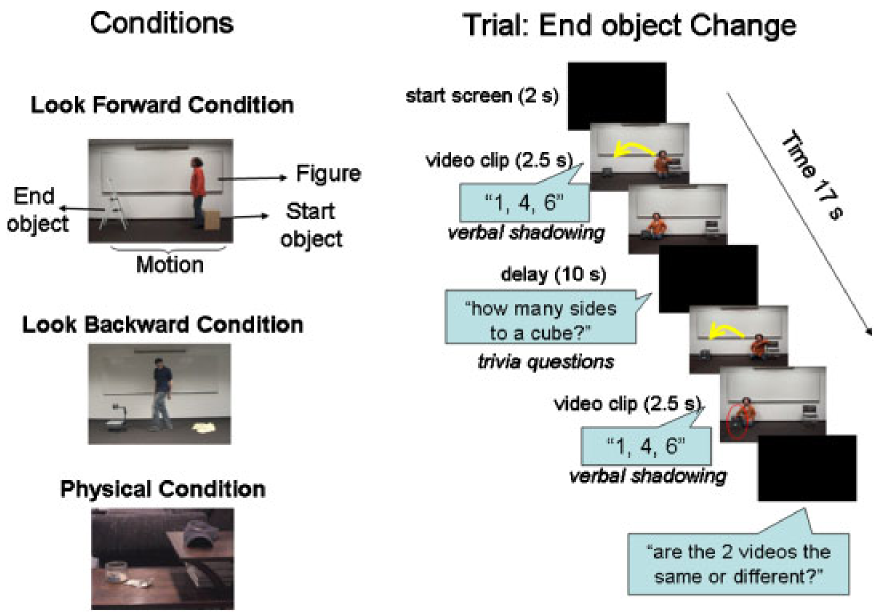

Figure 1. (**A**) Video stills from the three conditions and the elements that could change in "different" trials (Start object, Figure, Motion, and End object), (**B**) Trial design.

End object. This condition dissociated the direction of gaze from the direction of movement, providing conflicting cues about the person's goal. This manipulation enabled us to examine whether the two groups weighted movement and gaze cues similarly, and whether differences between groups reflected gaze direction per se, since the perception and interpretation of gaze are commonly reported deficits in ASD [Pelphrey et al., 2005].

Physical condition. These 32 motion events included an inanimate object (the Figure) being rolled ($N = 16$) or blown ($N = 16$) from a Start object to an End object. Start and End objects were real objects, such as a cup or folder. The moving Figures were objects that could be easily blown (e.g., tissue, leaf) or rolled (e.g., pen, battery) by an external force (e.g., a hairdryer positioned off screen). Similar to the other conditions, each of the 32 events had a "matched" event that was either the same video as the target event (No change; $N = 8$); or had a different Start object ($N = 8$), End object ($N = 8$), or moving Figure ($N = 8$). To confirm that the motion was not considered intentional, five adults were asked to describe the events and their descriptions were coded for mentalistic language [Heider & Simmel, 1944]. Mentalistic language was not used, confirming that these events were not considered animate by typical adults. This condition allowed us to examine whether the pattern of performance in the other conditions was specific to "intentional" events with people, or generalized to events with an inanimate Figure that was not construed as intentional.

Procedure

The method utilized a change blindness paradigm, expanding on evidence that people fail to notice all the information in a visual scene [Simons & Levin, 1997; Simons & Rensink, 2005]. Individuals saw two videos and had to decide if the videos were the same or different. In each trial (Fig. 1), participants viewed a video of a dynamic event for 2.5 sec, a black screen for 10 sec, and a second event for 2.5 sec, after which they judged whether the two videos were the same or different. The participant responded verbally and the experimenter circled same or different for each response. We also asked participants what had changed and recorded these answers. However, careful inspection of these answers did not yield any informative data because many people did not answer these questions, or had a difficult time reporting exactly what changed (e.g., item on the left instead of the actual object), consistent with previous work showing that changes are often detected before they can be accurately identified [Rensink, 2002]. Thus, we were unable to analyze the actual answers.

We wanted to ensure that participants utilized visual processes and did not rely on encoding the information linguistically. For example, participants might verbally represent all the objects in a scene by repeating "the man went from the desk to the ladder." If participants used this verbal strategy, even if they did not visually notice a change in the second video, they could go through each item (verbally encoded from the first video, i.e., "man, desk, ladder") to examine whether it was in the second video, thus detecting the change without using a visual representation. To ensure that participants did not use this sort of verbal strategy, participants were required to verbally shadow a sequence of numbers and words during the video clips. Such verbal output—repeating words out loud—makes it difficult to remember the items by repeating them verbally [see also Hermer-Vazquez, Spelke, & Katsnelson, 2008]. We also asked trivia questions during the 10-sec delay. Pilot data suggested that this manipulation, along with the delay, was necessary to prevent typical adults from performing at ceiling. It also ensured there was no verbal encoding during the delay.

Spatial span. Since the change detection paradigm has a significant working memory component, participants also did the spatial span to assess working memory. We administered the spatial span from the Cambridge Neuropsychological Test Automated Battery (CANTAB) via a desktop touch-screen computer (Mitsubishi Precise Point 8705). In this task, an array of white squares in a random pattern is presented. Some of the squares briefly change color and then return to white; participants are instructed to remember the location and the sequence of the squares that change color. Immediately after the final square returns to white, participants touch the squares that changed color in the exact sequence that they remember the changes having occurred. The number of squares to be remembered progressively increases from two to nine. Participants must perform one of the three trials correctly to progress to the next level of difficulty, which requires remembering one more square. Previous studies indicate that people with ASD perform more poorly than controls on this task [Luna et al., 2002; Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; Williams, Goldstein, & Minshew, 2005]. Thus, the inclusion of this measure as a covariate helps to control for general differences in working memory between groups in the analyses. This task was generally administered after the experiment.

Analyses. Since two of the trial type/condition combinations (i.e., Figure change, Look forward; No change, Physical) exhibited substantial negative skew in the distribution of the proportion of correct responses, the proportion correct data were transformed using a natural log on the reflected data [Kleinbaum, Kupper, & Muller, 1988; also thanks to Dr. Richard Lowry's very informative website at http://faculty.vassar.edu/lowry]. This transformed ''proportion of correct responses'' was more normally distributed and was used as the dependent variable.[1] The primary analyses used repeated measures ANOVAs. Since there was a trend for Age (Children, Adults) to interact with Group in this initial ANOVA, the sample was split into separate groups for further analyses using repeated measures ANOVAS. After these ANOVAs, planned comparisons examined group differences in each trial and condition separately, to test our hypotheses that scenes with people—and, more specifically, the objects of people's gaze and actions—might be represented differently in individuals with ASD. Finally, ANOVAs were used to examine developmental change separately in the typically developing group and the group with ASD.

While signal detection analysis could not be performed on this data (see footnote 1), the fact that performance was similar across groups on the no change trials suggests that all groups mistakenly identified a change when there was not one at similar levels. That this mistake occurred relatively often is interesting. A limitation of this current study is that we cannot be sure whether participants were correct about what changed when there was a change, or what they thought changed when they reported a change in the no change condition. Further work is needed to address these issues.

Results

Preliminary Analysis

Spatial span was significantly lower in individuals with ASD than in typically developing individuals ($t[72] = 3.28$, $P = 0.002$) consistent with previous studies [Steele, Minshew, Luna, & Sweeney, 2007; Williams et al., 2005]. Thus, in the ANOVAs described below, spatial span scores were used as a covariate to minimize the influence of working memory on the results.[2] Although well-matched on IQ, we also co-varied for full-scale IQ in the primary analyses.

Primary Analyses

Omnibus ANOVA. To examine the effects of group on performance in the change detection task, a repeated measures ANOVA was used. Group (2 levels; Control, ASD) and Age (2 levels; Children/adolescents, Adults) were between-subject factors. Condition (three levels: Look forward, Look back, and Inanimate) and, nested within Condition, Trial type (four levels: No change, Source change, Goal change, and Figure change) were within-subject factors. Both spatial span and full-scale IQ were included as covariates. The Greenhouse–Geisser corrected F values are reported, to correct for some violations of sphericity. This initial, omnibus ANOVA indicated a main effect of Condition ($F(1.99, 135.42) = 4.18$, $P = 0.02$), Group ($F(1, 68) = 4.84$, $P = 0.03$), and a trend for Age ($F(1, 68) = 3.61$, $P = 0.06$). Importantly, these effects were mitigated by a borderline interaction between Group and Age ($F(1, 68) = 3.17$, $P = 0.08$), suggesting that the divergence in performance between groups differed in children/adolescents and adults. No other factors were significant. Therefore, to better understand group differences, the two age groups were analyzed separately using repeated measures ANOVAs with the between-group factor of Group, within-group factors of Condition and, nested, Trial Type, with spatial span and IQ as covariates. When age in years was used as

[1]Signal detection analysis, taking into account the number of hits and false alarms, was not performed on these data because the no change trials (''false alarms'') were the same for all types of change trials.

[2]Two subjects with ASD did not take the Spatial Span task due to experiment malfunction; thus, these individuals are not included in the ANOVA. However, the pattern was similar when all participants were included, and spatial span was not a covariate.

a covariate, there was a trend for a main effect of Group ($F(1, 69) = 3.59$, $P = 06$) but none of the interactions reached significance. This lack of significance probably reflects, in part, that Age does not affect performance on this task in a linear, continuous manner, especially since this sample contains a substantial number of adults. A larger sample is needed to identify the true developmental trajectory, both typically and in ASD.

ANOVA—children/adolescents 9–18 years old (N = 23 per group). There were no significant main effects or interactions between Group, Condition, and Trial Type, including no main effect of Group ($F[1, 42] = .08$, $P = 0.78$). Exploratory analyses indicated that this pattern remained the same when the children (9 to 12; $N = 8$) and the adolescents (13 to 17; $N = 15$) were analyzed separately (Group effect, Children $F(1, 12) = 0.001$, $P = 0.97$; Adolescents $F(1, 26) = 1.0$, $P = 0.33$), though caution is stressed due to the small sample size of the child group (Fig. 2). Since there was such a large age range, we also performed an ANOVA with age as a covariate. This analysis also failed to identify a main effect of Group ($F(1, 41) = 0.73$, $P = 0.40$) or any interactions with Group, though there was a main effect of Age ($F(1, 41) = 5.07$, $P = 0.03$) on performance.

ANOVA—adults (N = 14 per group). A main effect of group indicated that adults with ASD performed more poorly than typically developing adults (Group: $F[1, 24] = 9.05$, $P = 0.006$). There was a borderline main effect of Condition ($F[2, 43.52] = 3.31$, $P = 0.05$), reflecting that performance was slightly better in Condition 2 (Look Back) than in 1 (Look Forward) or 3 (Physical) but post-hoc comparisons did not reveal significant differences between conditions (all Ps > 0.18). There was also an interaction between Group and Trial Type ($F[2.36, 56.53] = 3.19$, $P = 0.04$), indicating that group differences were more evident on some Trial Types than on others. The same pattern was evident when Age was used as a covariate (main effect of Group: $F(1, 23) = 9.06$, $P = 0.006$; Group × Trial interaction $F(2.35, 53.98) = 3.14$, $P < 0.05$). No other main effects or interactions reached significance. We tested our hypothesis—that individuals with ASD would be less sensitive to changes in potential goals—using planned comparisons, specifically t-tests to examine group differences on each trial type/condition combination separately. These analyses revealed that, regardless of condition, the group with ASD tended to perform more poorly than controls on the Start object change trials (Look forward condition, $t[19.9] = 1.98$, $P = 0.06$; Look back condition, $t[21.40] = 2.37$, $P = 0.03$; Physical condition, $t[24.92] = 3.12$, $P = 0.005$) and the End object changes trials (Look forward condition, $t[21.19] = 2.30$, $P = 0.03$; Look back condition, $t[14.86] = 4.84$, $P < 0.001$; Physical condition, $t[21.64] = 2.09$, $P < 0.05$). There was also a trend for a significant difference on the figure change trials in the Look back condition ($t[24.86] = 1.99$, $P = 0.06$) (Fig. 3).

ANOVA–development. To examine the developmental profile in the groups (TD and ASD) separately, we analyzed performance in each group using an ANOVA with Condition and Trial Type as within-subject factors and Age (children/adolescents, adults) as a between-subject factor. In typically developing individuals, this analysis revealed a main effect of Age ($F(1, 35) = 6.76$, $P = 0.014$), and borderline interaction between Age and Trial Type ($F(1.98, 69.55) = 2.91$, $P = 0.06$). Age did not interact with any other variables. Post-hoc comparisons using independent t-tests (equal variances not assumed) examined this interaction further. Improvements in typical development between childhood and adulthood tended to occur on the Start and End object change trials (though not in the End object trials in the Physical condition). Performance improved with age on the Start and End object trials in the Look forward condition ($t(34.9) = -2.67$, $P = 0.01$; $t(34.91) = -2.89$, $P = 0.007$) and the Look back condition ($t(34.9) = -2.07$, $P = 0.05$; $t(25.52) = -3.24$, $P = 0.003$), as well as the Start object trials in the Physical condition ($t(33.17) = -2.54$,

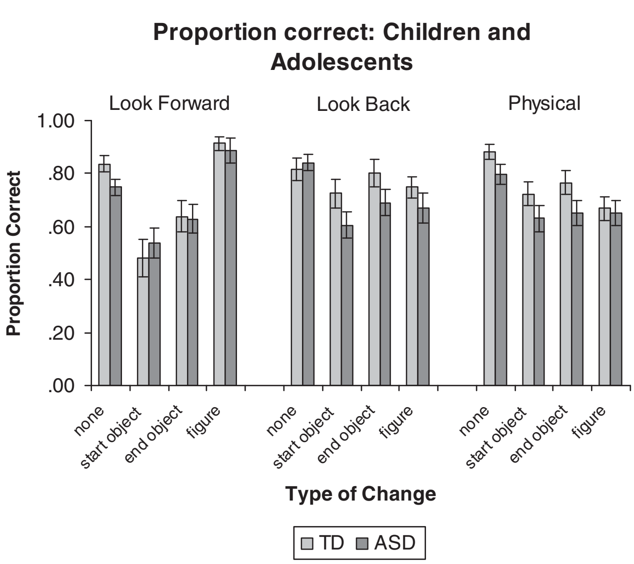

Figure 2. Proportion correct in children and adolescents.

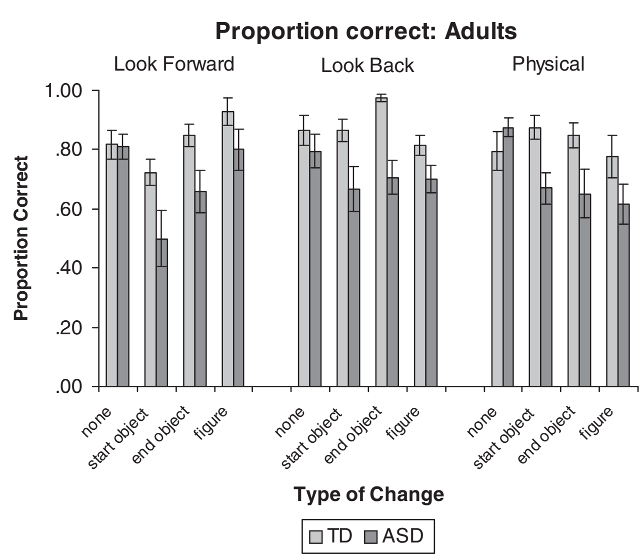

Figure 3. Proportion correct in adults.

$P = 0.02$). In the group with ASD, Age did not have a main effect nor did it interact with Condition or Trial (all $Ps > 0.47$). The pattern was the same when spatial span and full-scale IQ were used as covariates in each ANOVA. Thus, typically developing individuals improved with age, but individuals with ASD did not, on five of the six trial types that showed a significant difference between the ASD and TD groups in adulthood.

Object of gaze. To explore how gaze and movement cues affected change detection in individuals with ASD, and whether they weighted the gaze and movement cues similarly to typically developing people, we analyzed a composite score that compared change detection performance for Start and End objects. If movement is a stronger cue to what to look at than gaze, people should detect changes in End objects better than Start objects for both event types (Look Forward and Look Back); if gaze is a stronger cue, than this "goal bias" pattern would be evident in the Look forward but not the Look back condition. To examine these potential patterns, we computed a difference score on the accuracy (End object–Start object). To examine whether there were differences across Group or Age on this variable, we first did an ANOVA on this difference score with Condition as a within-subject factor, Group and Age as a between-subjects factor, and spatial span/full-scale IQ as covariates. While this analysis revealed a main effect of Condition ($F(1.97, 133.96) = 7.01$, $P = 0.001$), there were no main effects or interactions with Group or Age (all $Ps > 0.28$). To examine the Condition effect further, one sample t-tests were used to identify whether the difference score was significantly higher than zero. Changes in End objects were detected better than Start objects in both the Look forward and Look back conditions (control group, Look forward $t[36] = 4.09$, $P < 0.001$, Look back $t[36] = 3.77$, $P = 0.001$; ASD group, Look forward $t[36] = 2.74$, $P = 0.01$], Look back $t[36] = 2.23$, $P = 0.03$]), but not in the Physical condition, with an inanimate object as the Figure (control group $t[36] = 0.58$, $P = 0.57$; ASD group $t[36] = 0.24$, $P = 0.81$). Thus, overall, both groups were more likely to detect changes in the End object than the Start object when the Figure was a person, presumably because the intentional movement toward the End object was a strong indicator that this object was important. That this uneven pattern of performance also occurred in the Look back condition, when Figures were looking at the Start object, indicates that movement was a stronger cue than gaze as to which object was important in these videos. That this pattern did not occur in the Physical condition suggests that neither group viewed the End object of the inanimate Figure's movement as particularly important. In addition, it indicates that the better accuracy for the End object in the Look Forward and Look Back conditions was not simply a recency effect—if so, it should have occurred in all conditions.

Improvement across a condition.[3] One possibility is that participants may have learned what objects were likely to change, "priming" them to attend to these objects. To examine this possibility, we divided our data into the first third and last third of each condition; this analysis is exploratory, because each of these "thirds" contained between two and five trials of each trial type. We analyzed the data with Condition, Trial Type and Timing (first 1/3, last 1/3) as within-subject factors, and Group (ASD, controls) and Age (children/adolescents, adults) as between-subject factors. Timing had a significant main effect ($F(1, 70) = 93.00$, $P < 0.001$), but it did not interact with Group, Age, or Group × Age (all P's > 0.42), indicating that this effect was similar across groups. Timing did interact with both Condition ($F(1.86, 126.27) = 50.19$, $P < 0.001$), and Trial type ($F(2.35, 165.11) = 70.74$, $P < 0.001$); these affects are mitigated by a significant three-way interaction between Timing, Condition and Trial type ($F(1.96, 291.05) = 28.95$, $P < 0.001$). No other interactions were significant.

We then examined this three-way interaction using paired t-tests comparing performance on the first and last third of the trials in each condition/trial type combination. This analysis was carried out across the entire group, since the ANOVA indicated that timing affected different groups and ages similarly. We found that individuals tended to perform similarly across the first third and the last third of the no change trials (Look forward $t(73) = 1.34$, $P = 0.18$; Physical $t(73) = -0.33$, $P = 0.75$) with the exception of the difficult Look back condition ($t(73) = -7.42$, $P < 0.001$). Participants grew better at detecting a Figure change when the Figure was a person (Look forward; $t(73) = -9.27$, $P < 0.001$; Look back; $t(73) = -17.97$, $P < 0.001$) but not when the Figure was an inanimate object ($t(73) = -0.43$, $P = 0.67$). Participants grew better at detecting an End object change—what the figure was moving toward—when the person was looking at the End object ($t(73) = -4.14$, $P < 0.001$) but grew significantly worse when the person was looking at the Start object or the Figure was inanimate (Look back; $t(73) = 7.51$, $P < 0.001$: Physical; $t(73) = 2.87$, $P = 0.005$). They also became better at detecting Start object changes when the person was looking at the Start object ($t(73) = -6.55$, $P < 0.001$), grew worse when the Figure was inanimate ($t(73) = 3.24$, $P = 0.002$), and did not change significantly when the Figure was looking forward at the End object ($t(73) = -1.82$, $P = 0.07$). This analysis indicates that—as a condition went on—participants became more sensitive to people (as the Figure) and the object of their gaze, sometimes to the detriment of the other potential changes. Interestingly, this increasing sensitivity to people and the objects of their gaze (perhaps as participants noted the direction of gaze across a condition, as suggested by the reviewer) was similar across group and age.

Summary of the results. These results indicate that adults with ASD had difficulty encoding the Start and End objects in all conditions, regardless of whether the

[3]We thank an anonymous reviewer for suggesting this analysis.

condition included people (Look forward, Look back) or not (Physical). Adults with ASD are less sensitive to changes in these peripheral objects; the similarity across condition indicates that this difference does not reflect decreased sensitivity to human "goals" or intentions. This group difference was not evident between the children/adolescents with and without ASD. This result suggests there are typical developmental improvements when representing peripheral but still important objects (the Start and End objects) through adolescence, but that these improvements do not occur in ASD. This possibility was supported by our developmental analyses in each group separately, which showed significant development on these types of change trials in controls but not in ASD. The exception was End object changes in the Physical condition: adults with ASD performed more poorly than control adults on this trial type/condition combination, but there was not significant typical development. There was also a trend for adults with ASD to perform more poorly than typical adults at detecting Figure changes in the Look back condition. This insensitivity to a change in a moving person may reflect that this condition had conflicting cues (looking one way, moving another) that added complexity to the task, potentially making it more difficult for adults with ASD to represent all the potentially important objects. In addition to the group differences, these results also revealed some similarities between the groups with and without ASD. Both groups were more likely to attend to the End object than to the Start object in the people conditions (Look forward and Look back conditions), regardless of whether the person was looking at the Start or End object, but not in the Physical condition. This result indicates that both groups were more likely to use the "moving toward" cue, compared to the "looking at" cue, to allocate their attention.

Conclusions and Discussion

These findings indicate that adults with ASD have more difficulty than typical adults at detecting changes in all the potentially relevant objects in a scene: in particular, peripheral objects that the figure is moving to and from. The three conditions allowed us to examine whether the differences in ASD were specific to scenes with people or, even more precisely, the objects of people's gaze. In contrast to our hypothesis, adults with ASD performed more poorly than typical adults when detecting changes in the object at the beginning and the end of a movement, regardless of whether the moving object was a person or an inanimate object. Therefore, differences in adults with ASD in this paradigm are more likely to reflect their general visual profile [Dakin & Frith, 2005; Mottron et al., 2006] than difficulty in interpreting people's goals or actions. This impairment is consistent with recent evidence indicating that detection of the changes in marginal objects was impaired in adults with ASD, while detection of the central changes in a scene was similar to typical adults [Fletcher-Watson et al., 2006]. These authors suggest that individuals with ASD have difficulty attending to multiple objects, particularly when there is an engaging central figure, as in the current study. Decreased sensitivity to peripheral objects may impact the ability to interpret mental states, as understanding a person's goals often requires attending to peripheral and/or multiple objects (e.g., the object being gazed at; relations between objects).

No differences were found between children/adolescents with ASD and typically developing children, suggesting that the difficulties observed for adults with ASD may be attributed to "atypical" development. Specifically, in typical development, the ability to detect changes in the important but peripheral objects that a moving figure goes from and to generally tended to improve with age. There was no developmental improvement in detecting any type of change in the group with ASD, leading to impairments in detecting changes in the peripheral objects by adulthood. In addition, adults with ASD tended to perform more poorly than typical adults at identifying a change in the moving person when a person who was looking at one object but moving toward another. This limitation may reflect the incongruent cues to intentionality and what is important in the scene. In other words, the group differences when the person changed in this condition may reflect that attention needs to encompass multiple objects, as participants try to interpret the scene, and people with ASD have difficulty with this type of "attentional management". This result is consistent with prior evidence indicating that people with autism may have particular difficulty when gaze direction is inconsistent with their expectations [Pelphrey et al., 2005] and with more complex stimuli [Minshew, Luna, & Sweeney, 1999].

All groups paid better attention to changes in the "goal" object—the object the person was moving toward—than they did to changes in the "start object"—the object the person was moving from—but only when the moving figure was a person. This result suggests that people with ASD processed scenes with people relatively typically, attending well to the central person and the object that they were gazing at and/or moving toward, consistent with recent reports on the representation of people in ASD [Fletcher-Watson, Leekam, Benson et al., 2008; Fletcher-Watson, Leekam, Findlay et al., 2008; New et al., 2010]. However, there are limitations to the present study. Though dynamic, our scenes were relatively simple [compared to, for instance, New et al., 2010, or the real world]. It is possible that differences in ASD specific to viewing people would be evident with more complex stimuli, for instance, scenes with multiple people [Speer et al., 2007]. In addition, there are limitations to the change detection paradigm itself. In particular, in this present experiment, we could not ensure that the changes detected were indeed the correct changes. Many people detected changes on "no change" trials, and it is difficult to know what this response reflects. Clearly, more work needs to be done to examine whether this impairment in adults with ASD, and the pattern of development in the two groups, generalizes to other visual stimuli. In addition, little is known about the typical development of the neural substrates underlying visual processing of dynamic scenes, so it is difficult to guess what developmental changes might *not* be occurring in ASD. While speculative, we suggest that this type of visual processing might require the coordination of a large network of brain regions, including temporal and frontal regions. Other work indicates that network function has a long developmental trajectory [Fair et al., 2009; Luna et al., 2001] and might be affected by ASD [Just, Cherkassky, Keller, Kana, & Minshew, 2007; Minshew & Williams, 2007].

In summary, group differences were not specific to scenes with people, or objects of their gaze. While social deficits in ASD might affect the interpretation of social scenes throughout development, the currents findings do not appear to be associated with the social impairments in ASD per se. Instead, these findings seem to reflect less sensitivity in ASD to changes in peripheral but still important objects in a scene [and presumably less attention to them; Rensink, 2002]. This difference may reflect the distinct visual pattern, with a focus on individual elements, described in ASD [Brosnan et al., 2004; Dakin & Frith, 2005; Happe, 1999; Mottron et al., 2006]. This general visual difference may impact the interpretation of complex social scenes. Another scenario is that attention to social scenes supports late developments in attentional management [Rensink, 2002], leading to improvements during adolescence typically but not in ASD. That differences between groups became evident only with age is consistent with recent evidence indicating that late maturing visual processes are atypical in ASD, from both behavioral [Luna et al., 2007; O'Hearn, Schroer, Minshew, & Luna, 2010; Rump, Giovannelli, Minshew, & Strauss, 2009; Scherf et al., 2008; Scherf, Behrmann, Kimchi, & Luna, 2009] and neuroimaging [Lee et al., 2007; Raznahan et al., 2010; Scherf, Luna, Minshew, & Behrmann, 2010] methods. That these differences were only evident in adulthood suggests that interventions during adolescence may be helpful for visual differences that people with ASD find problematic. Finally, these results indicate that age differences across samples may contribute to the variability in the findings on visual processing. Further study using larger sample sizes and possibly longitudinal data will be helpful in examining the development of the ability to represent complex, real-world scenes in both typical and atypical populations.

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