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Detecting Social and Non-Social Changes in Natural Scenes: Performance of Children with and Without Autism Spectrum Disorders and Typical Adults

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Abstract We probed differences in the ability to detect and interpret social cues in adults and in children and young adolescents with and without autism spectrum disorders (ASD) by investigating the effect of various social and non-social contexts on the visual exploration of pictures of natural scenes. Children and adolescents relied more on social referencing cues in the scene as compared to adults, and in the presence of such cues, were less able to use other kinds of cues. Typically developing children and adolescents were no better than those with ASD at detecting changes within the various social contexts. Results suggest children and adolescents with ASD use relevant social cues while searching a scene just as typical children do.

Keywords Social attention · Development · Change detection · Change blindness · Naturalistic scenes · Visual perception

Introduction

One of the "core" defining characteristics of autism is social impairment, which is characterized by a lack of interest in people, awkwardness in social interaction, and inability to respond appropriately to social stimuli. Studies suggest that a lack of attention to social stimuli is the basis for a deficit in social perception, which could be at the heart of the social impairment. An important question therefore is whether perceptual and attentional deficits underlie social impairment in persons with autism. An intact social attention system would strongly constrain the scope of social impairment in autism, as it would suggest that there is not a failure to direct attention to socially relevant information in autism, but rather in the way the social information is utilized (e.g., persons with autism may not find social stimuli as intrinsically rewarding as typical persons, or, they may have difficulty using social information to regulate their own behavior).

In recent years, a number of reports have used the "flicker" paradigm to study limited aspects of social attention in persons with autism. This method, in which two pictures that differ only on a single detail are rapidly alternated separated by a brief flash (O'Regan et al. 1999; Rensink 2000, 2002; Simons and Rensink 2005), results in change blindness, a phenomenon in which the observer takes a much longer time than expected to locate the change in the image.

Using the change blindness flicker paradigm, Loth et al. (2008) showed that typical adults were far more able to

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detect scene-unrelated substitutions than scene-related changes, whereas adults with autism showed no such preference, and they were less able than typical adults to detect scene-unrelated objects. A set of studies by Fletcher-Watson and her colleagues measured change detection ability for objects and for direction of eye gaze, also in young adults with and without autism, and found no behavioral differences (Fletcher-Watson et al. 2006, 2008). That the ability to perceive change in others' gaze direction is intact in persons with autism is unexpected, in light of the fact that in natural situations children with autism fail to direct their attention according to the eye gaze of another (Loveland and Landry 1986; Mundy et al. 1986). However, as Fletcher-Watson et al. themselves admit, the fact that an able, adult sample was used rather than young children could explain their negative result. New et al. (2009) found that like typical young adults, children and adults with autism were faster at detecting change in animate versus inanimate objects, indicating persons with and without autism have similar attentional priority for animacy. These reports clearly point toward the need for utilizing the change detection paradigm to study social attention more extensively in children, a population for whom social attention is likely to be immature and for which a difference between autism and typical persons is likely to manifest.

Also using the change blindness paradigm, Kikuchi et al. (2009) studied facial versus object identity and facial versus object location in children; they claimed that children with autism, unlike their typical counterparts, lack an attentional bias for faces (they did not find a significant group x identity interaction, however). Change within a particular face (such as in its expression or direction of gaze) rather than change from one face to another is arguably a more social and natural type of change and would be an important follow-up experiment to confirm the idea that children with autism lack an attentional bias for faces embedded in naturalistic scenes. Burack et al. (2009) studied change detection of objects in children and found no difference in change detection ability in children with and without autism, but claimed a developmental trend toward improved performance in typical persons, but not in persons with autism (the authors did not statistically compare the error rate vs. mental age slopes of the two groups, however). It is important to investigate if a similar discrepancy in task performance between persons with and without autism spectrum disorders as a function of developmental level is found for detecting change over a wide range of social and non-social contexts.

From the seemingly inconsistent findings on adults and children on attention in natural scenes, it is clear that there is a pressing need to compare social attention in all its myriad forms in children with and without autism spectrum disorders. Indeed, social attention is a far from unitary phenomenon. Social cues in a scene such as pointing gestures could direct the viewer's attention to the environment and what is important in it, whereas cues such as others' facial expression afford social information about the other person, their state of mind and emotional well-being. Clearly, the ability to attend to one type of social cue does not necessarily predict the same ability to attend to another type of social cue. Therefore, one has to study a number of different changes in social cues and observe how children with autism fare on the various change types. Social cues can consist of such deliberate mechanisms as gestural joint attention (Tomasello 1995) as well as incidental observation of facial expressions, direction of gaze, proximity of persons to objects or other persons, etc.

Joint attention is an important type of social cue that remains to be investigated in change blindness studies of autism. Infants and young children use visual cues as a major mechanism of learning about the world through "social referencing" that guides their attention (Mumme et al. 1996; Walden and Ogan 1988). It is one thing to detect a change in gaze direction but yet another to detect a change indicated by gaze and attention-directing gestures in general. The latter is an important type of social cue that needs to be studied and compared with other social cues, e.g., change in facial expression/direction of gaze. In light of past studies on the development of attention in children with and without autism (Burack et al. 2009), it is also important to chart the development of social attention as a function of chronological age as well as developmental level. In this light, comparing the performances of children with adults could prove instructive, as the less developed social ability of children compared with adults as reflected in performance on the change detection task could provide a useful benchmark for potential findings of a deficit in social attention in autism. For instance, if the performance of children compared with adults is lower on one type of social cue change but children with and without autism do not differ on this same social cue change, this would suggest not only that children have less developed attention to that particular social cue than adults do, but that any social deficit that exists in autism cannot be ascribed to a deficit in social attention specific to autism.

In light of the above unresolved issues, our study employed the change blindness flicker paradigm to compare the social attention capabilities of different groups of individuals—children and young adolescents (hereafter, *children*) with and without an autism spectrum disorder (ASD), and typical adults. Our aims were (a) to determine how the presence, absence or specific context of different types of social cues in a scene affect the way persons with ASD visually detect changes; and, (b) to determine whether performance on the change detection task differs between children and adults. We hypothesized that if, as earlier studies have found, persons with ASD attend less to attention-directing gestures and to the eye region of faces, then it would be more difficult for them than for other participants to discover changes in the scene that are related to these types of cues. However, if social cues in the scene are unrelated to the target change or actually serve to direct attention away from it, we hypothesized that persons with ASD would instead discover changes more readily than typical participants, whose attention would be temporarily misdirected by the social cues.

Finally, we compare children with adults. Children do not possess the sophisticated social skills of adults. We speculate that part of the reason for this is that attention toward social cues is still developing as the child matures. Consistent with this point, we reason that typical young adults would perform better than both children with and without autism in detecting change in social scenes, which are characterized by interactions between different persons in the scene or between a person and the environment. Specifically, we hypothesize that children will not do as well as adults when the facial expression or direction of gaze of a person in the scene changes, or when an object that is attended to (via pointing gestures or gaze) by a person or persons in the scene changes, but will do as well when no people are present, i.e., there is no social content in the scene. Experimental support for this hypothesis would indicate that the ability to attend to and utilize social cues rapidly and efficiently continues to develop past early childhood, as has been claimed for attention in general.

Methods

Participants

Both adults and children participated. Adult participants were forty (13 female) healthy college student volunteers (22.2 ± 0.4 years, age range: 19–27 years) with normal or corrected-to-normal vision. Children were 40 (13 female) healthy children and adolescents (10.6 ± 0.4 years, age range: 6 years, 10 months–15 years, 6 months) (hereafter referred to as children) with normal or corrected-to-normal vision. Of the sample, 22 had existing clinical diagnoses of an autism spectrum disorder (ASD) (autism: 12, Asperger's: 4, PDD-NOS: 6; 10.5 ± 0.5 years, age range: 6 years, 10 months–15 years, 6 months), and were intellectually able and thus able to understand our instructions and successfully perform the experimental task (mean ± SEM. IQ using the Stanford-Binet-5 test was 98 ± 4). Before enrollment all were confirmed as having an Autism Spectrum Disorder for the purposes of this research study by use of the Autism Diagnostic Interview (ADI-R) and the Autism Diagnostic Observation Schedule (ADOS), administered by investigators who had been trained to research reliability on these instruments. Final judgment of the diagnostic classification was the responsibility of the last two authors (DAP, KAL). The remaining 18 were typically developing children (TD) (IQ was 107 ± 6; 10.8 ± 0.6 years, age range: 7 years, 4 months–15 years, 0 months), none of whom had a history of any known developmental differences according to parent interview. All were naïve to the study's specific purpose. The study was approved by the local human subjects protection committees of the University of Houston and the University of Texas Health Science Center at Houston, and all participants and/or their parents gave written informed consent.

Stimuli

Stimuli were photographs of human models and objects in indoor scenes. Since both the visual saliency of target objects and the incongruity of objects with the rest of the scene affect the inspection of pictures (Underwood and Foulsham 2006), we created scenes in which no objects violated the gist of the scene. Photographs were taken by the investigators with a Canon PowerShot G4 digital camera set to take high resolution photographs and mounted on a tripod for stability. All venues were well-lit with natural, ambient lighting. No flash was necessary for the photography. The bitmap files obtained were typically 2,272 × 1,704 pixels in size; however, a small handful of images were cropped to remove distracting objects, such as bright light sources, and thus had fewer pixels. Images were uploaded onto a Windows XP computer (HP Pavilion) and shown on a ViewSonic G225f monitor. All pictures subtended the entire screen viewing area—40.8 × 30.6 cm.

Pictures were shot in pairs. There were two kinds of picture pairs. Change trials were pairs of pictures that differed in one important scene detail. The participant's task was to respond when they identified the change in between the two pictures. Catch trials were those that used two photographs of an unchanged scene. The correct response in catch trials was not to respond at all until the trial timed out.

Setup

On each trial, a pair of photographs alternated on the screen as follows: (a) Picture 1: 240 ms; (b) Inter-stimulus interval, or ISI (blue screen): 80 ms; and (c) Picture 2: 240 ms. Each trial (a + b + c = 1 trial, 560 ms; total maximum duration = 15.12 s; 27 alternations × 560 ms/alternation) terminated once the participant made a choice, or until a

Table 1 Experimental conditions: change trials

Condition number	Condition name	Condition description	Example of a change trial	Number of trials
1	No human	Target change not connected with humans, no humans present	Coat hanging on coat rack disappears	7
2[a]	Human- unrelated object	Target change not connected with humans, but humans present	Coat hanging on coat rack disappears. Human(s) on chair with eyes closed, far from rack	8
3	Human-related object	Target change connected with humans	Coat on person's shoulder disappears	8
4	Attended object	Attention directed to target change by a human action (looking, pointing)	Human on chair points to coat on coat rack, sweater disappears	8
5	Non-attended object	Misdirections away from target change by a human action (looking, pointing)	Human on chair points to coat rack, sweater elsewhere (e.g., on desk) disappears	9
6	Human face	Social-emotional target change (change in facial expression or gaze)	Human on chair shifts eye without moving head or rest of body	10

[a] On change trials of condition 2, the actor(s) was not looking anywhere in the scene, e.g., the person's back was turned, (s)he was asleep, and so on

time-out (i.e., maximum duration reached). A new scene was presented on each trial. A total of 62 trials were presented in 7 blocks, including change trials and catch trials. Each block contained 8 or 9 trials, and included one or two change trials for each of the six conditions described in Table 1 and 1–3 catch trials (Table 2).[1] There was a 3,000 ms interval between blocks during which a blue screen was displayed. Across participants, presentation order of the picture pairs in an individual block was the same, but block order was random.

The experiment was scripted in MATLAB (Mathworks, Inc.) using the Psychophysics Toolbox extensions (Brainard 1997; Pelli 1997). In order to get participants familiar with the apparatus and procedure, participants were required to run a practice session that consisted of 6 trials. Experimental parameters were the same as in the actual experiment. The picture pairs used in practice were not re-displayed in the actual experiment later.

Conditions

Change trials were categorized into one of six conditions, depending on the nature of the target change and scene context (Table 1). The target could be (a) either a change in a person in the scene or in some object connected with a person (conditions 3, 4 and 6), or (b) a change in an object in the scene not connected with a person (conditions 1, 2 and 5). Catch trials were included to help detect the amount of the participant's guessing and to encourage enhanced reliability of change identification. Change and catch trials are described with examples in Tables 1 and 2 respectively. No two trials had identical scene or target (the examples cited in Tables 1 and 2 are for illustrative purposes; see Supplementary Fig. 1 for example of change image pairs corresponding to each condition). As a result, there was little effect of familiarity to scene or target that could carry over to later trials.

Task

In order to familiarize participants with the types of scene, kinds of change, and task, all participants first were trained on the task using trial stimuli to insure that they understood it and were able to perform the necessary actions while attending to the computer screen. More specifically, each participant ran six practice trials—each selected to exemplify a different type of change/no change. The task was identical to that in the actual experiment that immediately followed the practice. At the end of each practice trial, visual feedback was provided that made clear the location and type of change. Participants were also instructed that there were catch trials on which no change occurred. On trials on which the participant did not notice any change at all, (s)he was not to make any response until the expiration of the 15 s time limit. In this way, participants were made aware of the different types of changes that could occur and that changes occurred in some but not all trials (the exact fraction of trials was not specified). Performance on practice trials was not analyzed.

In the experimental task, participants searched for the target change and signaled that they had found it by clicking a computer mouse. The RT measure was the time at which the mouse click occurred. The images were

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[1] We selected as many picture pairs of a given condition as met our criteria, which is the reason for the unequal numbers of trials across the different conditions.

Table 2 Experimental conditions: catch trials

Condition number	Condition description	Example of a catch trial	Number of trials
1	No humans present in a scene full of inanimate objects	Coat hanging on coat rack. Nothing changes	3
2, 3, 6	Humans and inanimate objects present in scene	Coat hanging on coat rack, humans present. Nothing in scene changes	4
4, 5	Attention directed by humans in scene	Human on chair points to sweater on coat rack, nothing in scene changes	5

flickered until a response was recorded or until 15 s had elapsed, which is the time limit used in a previous change blindness study of autism (Burack et al. 2009). The time limit was constant across trials. Following the mouse click, the participant had to verbally describe the change to the experimenter. For the trial to be classified as correct, the participant had to verbally identify or locate the change (the target). Correct identification of the target item in the scene that changed, disappeared, or moved was designated as a correct response. Trials in which the participant made a mouse click response but did not correctly identify the type of change and the item in the scene that changed were scored as a miss. Overall, we were conservative in determining correctness, and unclear or ambiguous responses were not given the benefit of the doubt (e.g., "the marker changed" in a scene in which the marker changed color was scored incorrect). The experimenter evaluated and recorded the correctness of the response. Response times (RT) were directly measured by the software.

Analysis

The performance of each participant on the change trials of each of the six conditions was measured in two ways—(a) percentage correct (% correct), and (b) response time (RT). Only RTs on correct change trials were considered. On change trials in which the observer correctly responded just as the 15 s time limit expired (i.e., when the observer forgot to first click the mouse but rather, in haste, verbally described the change while time was expiring—this occurred rarely), the trial was counted as a hit (correct) and RT on the trial was capped at 15 s. Catch trials were separately analyzed. To guard against possible speed-accuracy trade-offs, response times (RTs) and error-rates were combined for each participant and condition into an established single parameter termed *inverse efficiency*: mean RT divided by % correct (Townsend and Ashby 1983). Inverse efficiency scores were primarily used in our statistical analysis. RT and % correct were separately analyzed as well to obtain a finer-grained picture of between-group differences. For each subject, inverse efficiency values were transformed into z-scores for each condition (i.e., image class) using the formula below.

$$z\left(\mathrm{IE}_i^j\right) = \frac{\mathrm{IE}_i^j - E\left(\mathrm{IE}_i^j\right)}{\sqrt{\mathrm{Var}\left(\mathrm{IE}^j\right)}}$$

where IE_i^j is the inverse efficiency score on condition (image class) i for participant j and $E(.)$ is the expected value or mean of inverse efficiency scores for the participant j.

Statistics

A two-way ANOVA was conducted with group and conditions as factors (SPSS, v11.5). We compared the ASD and TD child and adolescent groups. We also compared adults with children (ASD and TD groups combined), and adults with TD children alone. Post hoc pairwise comparisons used the t test with Bonferroni correction for multiple comparisons. A p value of 0.05 defined significance. To compare image statistics such as contrast across condition, a one-way ANOVA with unequal replication (the number of change trials in each condition varied slightly) was performed.

Results

Table 1 lists the six conditions tested and gives an example of each (also see Suppl. Fig. 1 for images from representative change detection trials from each condition).

ASD vs. TD

First, we examined differences between the ASD and TD groups on the different conditions. We did not find a statistically significant difference in performance between children with ASD ($n = 22$) and TD children ($n = 18$) on the inverse efficiency measure (Fig. 1): A mixed-model ANOVA revealed no significant effect of group ($F(1, 38) = 0.51$, $MS_e = 333.84$, $p = 0.481$), and no significant group × condition interaction ($F(5, 38) = 0.81$, $p = 0.373$), indicating no statistical difference overall or on any

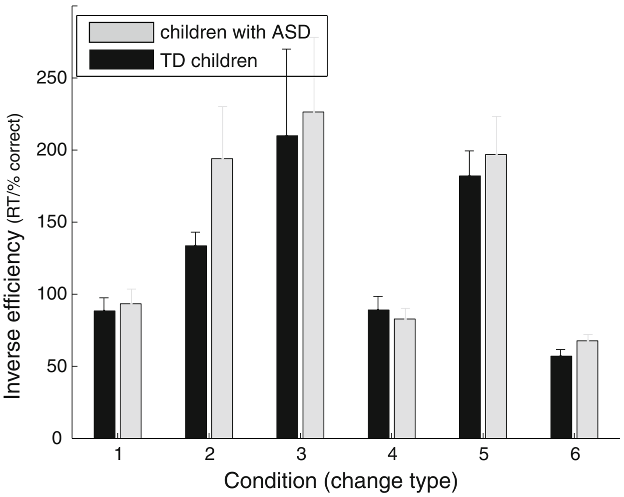


Fig. 1 Performance on visual change detection of children with autism spectrum disorder or ASD versus typically developing children, or TDs. Mean ± SEM inverse efficiency index values (RT, measured in ms/% correct) for ASDs (*gray bars*) and TDs (*black bars*) on each of the six conditions tested are shown. Smaller values of inverse efficiency indicate superior performance

of the six conditions between the two groups of children. A pairwise comparison of performance between the two groups of children also yielded no significant differences on any of the six conditions (uncorrected $ps > 0.1$ on all comparisons, t-tests). Limiting correct trials to those in which participants responded before 15 s elapsed also yielded no differences (see Supplementary Materials). A separate analysis of speed (RT) and accuracy (% correct) also did not yield any statistically significant differences between the two groups of children, overall (RT: $F(1, 38) = 0.30$, $\mathrm{MS_e} = 9.46$, $p = 0.587$; % correct: $F(1, 38) = 0.930$, $\mathrm{MS_e} = 0.107$, $p = 0.341$), or on any specific condition (RT: $F(5, 38) = 0.568$, $p = 0.724$; % correct: $F(5, 38) = 0.30$, $p = 0.910$). Thus, no reliable differences were observed in any of the social or non-social attention conditions between children with and without autism, in line with past studies using a change detection flicker technique in adults with autism (Fletcher-Watson et al. 2006, 2008; New et al. 2009).

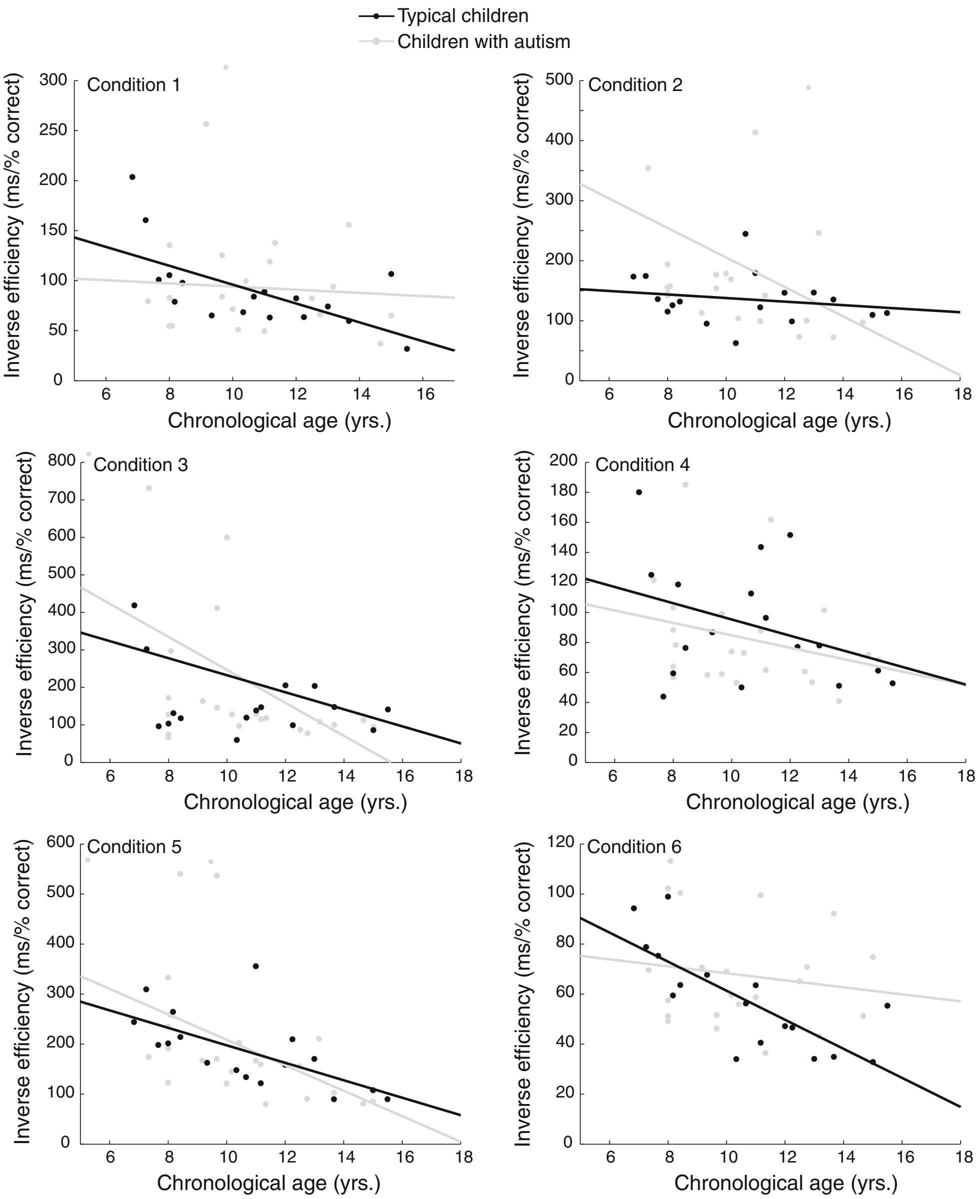
It is possible for within-individual variability in performance across condition to mask underlying differences between groups on a given condition. In order to address this possibility, inverse efficiency values were first transformed into z-scores for each condition (i.e., image class) on a per subject basis (see "Methods") and then compared. Once again, we did not find significant differences between children with and without autism on any of the six conditions tested (uncorrected $p > 0.1$ on all comparisons, t-tests). Thus, controlling for within-individual variability did not affect the basis result: performances of children with and without autism do not differ either on the social or the non-social change conditions.

There is also the possibility that performances could be influenced by "location priming". In other words, if participants become aware that changes recurrently relate to, say the eyes of the actor(s) or their face, this expectation would alter the way they regard the images in subsequent trials. Furthermore, the degree to which one learns or acquires this form of meta-cognition could differ between children with and without autism. In order to address this possibility, we divided trials into half depending on the order in which a given participant saw them and examined whether performance improved on the later trials as compared to the earlier ones on any of the six conditions in children with autism and in TD children. Tests revealed no statistical change in inverse efficiency on any of the original six conditions for either of the two groups studied individually (all uncorrected $ps > 0.1$). Even after combining data from all children, with or without autism, we did not find a statistical improvement on any condition whatsoever (all six uncorrected $ps > 0.1$). Although this was a negative finding, it is encouraging nonetheless in that it suggests that performance on our change identification task is uncontaminated by learning, at least over the brief time course of a single experimental session.

In our experiment, change trials were classified on the basis of the relationship between people in the scene and the change, thereby using social interaction as a guide for categorization. Studies of change blindness, which do not typically study social attention, use a different classification scheme based on change type, i.e., if an object in the scene appears/disappears, changes size, shape or color, or if it moves. We wondered if this classification scheme could uncover latent differences between children with and without autism. For this purpose we re-classified trials into four types: (1) appearance/disappearance, (2) movement, (3) change in object form or shape or (4) change in object color/texture/size, which does not fundamentally alter the object. However, even under this new classification scheme, no differences were observed between the two groups of children on any of the four new classes (all uncorrected $ps > 0.4$).

Finally, we investigated whether there was a developmental trend in change detection performance in children with ASD and TD children and also whether the two groups of children differed developmentally on a particular condition or change type. For the two groups of children separately, we correlated participants' chronological age with performance (inverse efficiency scores) on each change type (Supplementary materials discusses results on correlations of mental age derived from FSIQ scores with performance on each change type). As Fig. 2 shows, for both TD children as well as for children with autism, a

Fig. 2 Correlations between inverse efficiency values and chronological age for children with autism (*gray points* and *line*) and typically developing children (*black points* and *line*) for the six different change types



negative relationship between age and inverse efficiency was observed on nearly all change types. This result implies improvement in change detection with chronological age. For TD children, the slopes significantly differed from zero on change types 1, 5 and 6 ($p < 0.05$, Bonferroni corrected). For children with ASD on the other hand, the slopes significantly differed from zero on none of the change types. These findings are apparently consistent with past studies (Burack et al. 2009). However, the inverse efficiency versus chronological slopes were not always more negative for the TD children (conditions 2 and 3), which suggests that change detection does not generally improve more with age in typical children than in children with autism. This was confirmed when, unlike past studies, we statistically compared the slopes for the two groups: there was no significant difference in slopes on any of the six change types, although there was a trend on condition 6 ($p = 0.07$, uncorrected), suggesting that TD children, more so than children with ASD, improve in detecting change in facial expression with age. In sum, developmental differences on change identification between children with and without autism are small and insignificant across the ages included in our child samples and do not appear to indicate major differences across development between children with and without autism.

Adults vs. Children

We next compared the performance of our child/adolescent groups with that of a group of typical young adults. In comparison with adults, the social skills of children are clearly developing. We compared the two groups (adults vs. children) in order to determine that the change detection task we used was sensitive enough to uncover differences in social attention ability between groups of individuals whose social abilities are known to differ.

Because no differences between the two groups of children were observed in overall performance or on any of the individual conditions, data from both groups were combined in comparisons with the young adults. Specifically, we compared the inverse efficiency values of adults ($n = 40$) and children ($n = 40$; Fig. 3a). A mixed-model ANOVA with group and condition as the two main factors revealed a significant main effect of group ($F(1, 78) = 14.83$, $MS_e = 120.04$, $p < 0.001$), as well as a significant group × condition interaction ($F(2.79, 78) = 5.678$, $p = 0.001$, Greenhouse-Geiser corrected). Post hoc t-tests, Bonferroni corrected for multiple comparisons, revealed that children were significantly less efficient at identifying change than were adults on the human-related object condition 3 ($p < 0.005$, Bonferroni corrected), the misdirection of attention condition 5; ($p = 0.001$, Bonferroni corrected), and on the human face expression/gaze change condition 6 ($p = 0.012$, Bonferroni corrected). Adults were marginally better than children in identifying change when it was not related to the person(s) in the scene (condition 2; $p = 0.10$, Bonferroni corrected) as well. Separate analyses of accuracy (% correct) and speed (RT) as a function of condition further revealed that children were significantly less likely to correctly identify the change than adults on conditions 3, 5 and 6 (all three corrected $ps < 0.001$), and significantly slower than adults in identifying the change whether or not it was related to actor(s) in the scene (conditions 2 and 3, both corrected $ps < 0.001$).

A comparison limited to typical adults and typical (TD) children yielded a similar finding (Fig. 3b): TD children were significantly worse than TD adults at identifying change *only* when there was a misdirection of attention away from the target (condition 5; $p = 0.004$, Bonferroni corrected), or when the target was related to an actor(s) in the scene (condition 3; $p = 0.017$, Bonferroni corrected). We further studied accuracy (% correct) and speed (RT) to dissect more closely the differences observed between the two groups: TD children were significantly less accurate than adults on conditions 3, 5, and 6, and significantly slower than adults on conditions 2 and 3—findings identical to those obtained from comparing all children combined with adults.

In the context of the positive findings of differences between children and adults on conditions 2, 3, 5, and 6, it is important to reiterate the negative findings. That is, when comparing performance when identifying change when no people were present in the scene or when the object pointed to in the scene changed—conditions 1 and 4, respectively—no significant differences in inverse efficiency, accuracy (% correct), or speed (RT) were observed between the various groups—children with ASD versus those without (TD children), children versus typical adults, TD children versus typical adults, or even children with ASD versus typical adults.

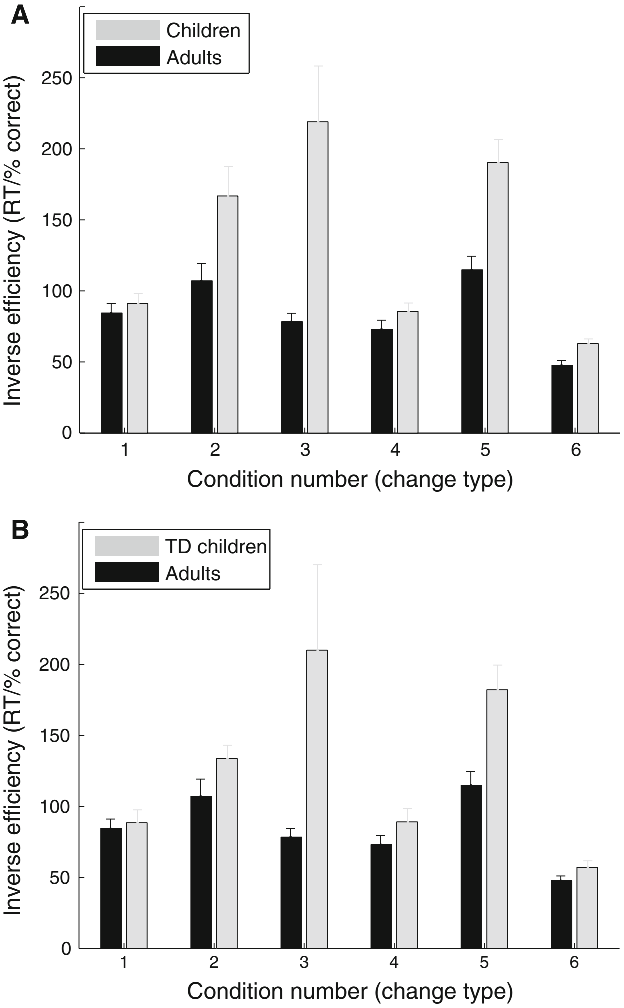


Fig. 3 Change detection in adults versus children. **a** Mean ± SEM inverse efficiency index values for children (*gray bars*) and adults (*black bars*) are shown. **b** Mean ± SEM inverse efficiency index values for TD children (*gray bars*) and adults (*black bars*) are shown

The lower performance of children compared with adults on certain change types cannot be explained by the possibility that children were simply less efficient at detecting those changes that adults themselves found most difficult: children were highly significantly worse than adults at spotting change when facial expression/gaze direction changed but adults found the same image class the easiest to detect change in, as compared to each of the other five image classes (all corrected ps < 0.001; Indeed, every group we studied—typical adults/TD children/ASD children—found it significantly easier to detect changes such as eye gaze or expression than any other type of change, with the sole exception that children with autism performed comparably on the directed attention condition). On the other hand, children were no worse than adults in detecting change to an object to which actors in the scene attended, although detecting that type of change was more difficult for adults (as well as for children) than detecting change in facial expression/gaze direction.

In sum, children were less efficient than adults in identifying change when actors were present, regardless of whether the changing item was related to them (2) or not (3), when the viewer's attention was directed away from the change (5), and when facial expression/gaze of a scene actor changed (6), but were no less efficient when there were no people in the scene (1) and when actors in the scene directed the viewer's attention toward the change (4).

Finally, the difference in change detection between children and adults has implications for the comparison between children with and without autism. Children with autism did not do worse in detecting any of the various social types of change than their typically developing counterparts, for which an argument could be made that performance on the various social types was at ceiling, obscuring differences between the two sub-groups of children. However, as indicated by the significantly worse performance as compared to adults, children still had room to improve on at least one of the social conditions, namely facial expression/gaze direction change, clearly undermining the ceiling effect argument.

Discussion

Change detection is a powerful means to study attention in natural scenes (O'Regan et al. 1999; Rensink 2000), and has been successfully employed as a tool in the study of social attention, including in persons with and without ASD (Burack et al. 2009; Fletcher-Watson et al. 2006, 2008; Kikuchi et al. 2009; Loth et al. 2008; New et al. 2009). On the basis of these studies, adults with ASD, like typical adults, have been found to attend preferentially to animate categories and social cues, and to attend less to scene-unrelated objects than typical persons, and children with ASD, unlike typically developing children, have been found to lack an attentional bias toward faces. Here, we have extended the application of change detection to examine attention in children with and without autism, and in adults versus children, to different types of social and non-social cues, including directed attention and misattention, facial expression, items related to or unrelated to actors in a scene. In the following sections, we discuss our results in the context of past studies on change blindness, social attention and/or autism, and speculate about some implications.

Adults Versus Children

Our study revealed children were less able than young adults to detect certain kinds of change, namely when the changing target was closely tied to a person or persons in the scene, when actors in the scene attended to a non-changing object, when the target was not connected to any of the actors in the scene, and when an actor's face changed expression or gaze. Children were no worse than adults in detecting the change when an actor(s) attended to the change, or when the changing item was embedded in a scene that had no people in it.

There are several possibilities why children were less efficient than adults in detecting certain kinds of change. Pictures from the different image classes could have differed in some low-level properties making some conditions inherently different from others. However, analysis of low-level image measures did not support this possibility (see Supplementary Materials). Moreover, we did not find that children with autism were similarly less efficient than typically developing children on certain kinds of change. Therefore, some reason other than difference in image class is likely to be responsible for the differences between adults and children.

A second, and more interesting, account is that children who are generally less adept socially than adults as a whole, are therefore less efficient at perceiving social cues and less likely to detect social types of change. This is supported by our finding that children were less likely than adults to detect change in facial expression or gaze within a prescribed time. However, among all conditions, children, like adults, were best at detecting change in facial expression/gaze. In addition, children were less efficient than adults at detecting change on a host of other conditions that cannot be accounted for by social shortcomings, e.g., change in an item that has no relation with anybody in the scene. Therefore, a more general account that will encompass inefficiencies in children on multiple different change types must be considered.

One such account is developmental difference: in a static scene containing social cues, children's attention, just as adults', is riveted toward these cues, but that children are less efficient than adults in shifting their attention to other items in the scene. Consistent with this account are our findings demonstrating that children were not less efficient than adults in detecting change when actors in the scene attended to the changing object but were when actors attended to a non-changing object (condition 5). That is to say, children's attention was "captured" by the gestural cue, and unlike adults, children were not as able to re-direct their attention away from the cue when it was misleading.

Other findings of ours further bolster the attention capture account: Children (all children, or only TD children, regardless) were less efficient than adults at detecting change in an object that was somehow linked to the actor's person (e.g., a ring on an actor's finger or a blanket in the actor's lap) or when the changing object was not connected to the persons in the scene in any way. Pictures of these conditions (2 and 3) clearly differed from those of the other "social" conditions because there was no social referencing even though there were actors in the scenes. Because there was no social referencing depicted in these pictures, the children's attention remained on whatever they were initially drawn to, rather than shifting to locate the changing object. Of interest is the fact that children were no worse than adults in detecting change in an object when no persons were present in the scene (condition 1), i.e., when there was no social referencing at all. All of the above findings are consistent with the idea that children rely heavily on social referencing to make sense of the environment. Thus, when these social cues do not convey the information about the environment that they need, as is the case in conditions 2, 3, and 5, it is more difficult for children, compared with adults, to ignore them.

In sum, our findings suggest the following. Children, like adults, attend preferentially to social cues. Unlike adults, children are over-reliant on social referencing cues while viewing a scene and therefore, they are unable to shift their attention away. Whereas children efficiently process social cues to understand the world around them (which explains their adult-level ability to detect change that actors in the scene attend to), they do not process social cues as efficiently to understand other people (which explains their poorer ability to detect change in facial expression or gaze). To wit, over-reliance on social referencing and underdeveloped social attention in children are not mutually exclusive.

The attention capture account of development is not complete, however. If an over-reliance on social referencing is responsible for the difference between children and adults, then one would also expect—in light of the known difference in joint attention skills between children with autism and typically developing children—to find a similar difference in change detection ability between children with and without autism. We found no such difference, however. Nonetheless, it is possible to reconcile the account for the children versus adults data with the TD vs. ASD children data in a number of speculative but plausible ways: For instance, under task-free conditions while the child with autism is visually exploring the environment, his/her attention may be naturally drawn toward non-gestural joint attention cues in the environment. However, under task conditions when detecting the changing target in the scene is of paramount importance, the child with autism will behave like a typically developing child and will actively attend first to social cues. Alternatively, the dynamic nature of the social referencing cues in the real world (e.g., gestures are rapid-fire staccato bursts of limb and face movements) that may render it difficult for the child with autism to focus on them. In our task on the other hand, the social referencing cues are embedded in a static scene, rendering it easier for the child with autism to attend to these salient cues first in the same manner as would a typically developing child. Future studies will test the viability of these and other interpretations.

The present study extends recent studies that have examined the development of change blindness in children. Children have reduced sensitivity to the details of objects (Shore et al. 2006) but otherwise, like adults, detect semantically important changes more quickly and accurately than semantically less important changes (Fletcher-Watson et al. 2009). A straightforward conclusion from these studies is that our tendency for more accurate detection of change for items of central than marginal interest (Rensink et al. 1997) is more pronounced in children. Our work goes beyond these studies by examining social attention in finer detail under a variety of different conditions, leading to the idea that social cues are of central interest to children, and that children are hyper-reliant on social cues for understanding the world (but not necessarily other people's emotions) at the expense of putatively marginally interesting, non-social items.

Autism Versus Typical Groups

Unexpectedly, we failed to find significant, substantial differences in performance between children with and without autism on any of the different change types. Eye movement studies of autism have found clear differences in scan patterns: when viewing naturalistic social situations such as ours, individuals with autism exhibit abnormal patterns of social visual pursuit consistent with reduced salience of eyes and increased salience of mouths, bodies, and objects (Klin et al. 2002). In comparison with matched controls, 2-year-old children with autism look significantly less at the eyes of others but significantly more at the mouths (Jones et al. 2008). One would expect that a difference in eye movement scan patterns would behaviorally manifest in a change detection paradigm, specifically that children with autism would excel in situations not containing any social interaction (e.g., condition 1), but fare worse than typical children when attention to the face, or gestures, of the actors in the scene is demanded (e.g., conditions 4, 6). As indicated by their slightly poorer performance in detecting change in face identity or location, children with ASD were shown to have a weaker attentional bias toward faces as compared to matched typically developing children (Kikuchi et al. 2009). A straightforward extension of this would be a poorer ability to detect change in facial expression/gaze in children with autism than without. To our surprise, we did not observe any of these predicted differences across a wide choice of performance measure—inverse efficiency, *z* scores, reaction times, % correct, d-primes, and so on.

Our findings appear to differ from studies that have found a difference in social attention between persons with and without autism. However, there are some differences in the stimuli used, which might be important. Kikuchi et al. (2009) studied change in face identity and location on the computer screen, whereas we studied change in facial expression in addition to other social and non-social change types. Facial expression and gaze provide important social cues to the viewer about the scene that facial identity (in their study, a face of a stranger was replaced by the face of another stranger) or screen location might not, which could override the reduced attentional bias for faces in persons with autism. This difference in stimuli between the two studies might underlie the discrepancy in their findings. It bears mention that although change detection was no different statistically between children with and without autism on any of the six different change types in our study, the largest difference, albeit an insignificant one ($p = 0.12$, uncorrected), was on the facial expression change condition, which is of the same order statistically as Kikuchi et al.'s (2009) weak effect on the face identity condition.

On the other hand, our findings are in accord with a number of studies of attention in persons with autism using the change blindness paradigm that, like us, did not find a significant difference between persons with and without autism. Fletcher-Watson et al. (2008) found that adults with ASD, like typical adults, were both faster and more accurate to detect a change involving eye gaze than to detect a control change in a complex scene, and otherwise showed normal selection of items for attention (Fletcher-Watson et al. 2006).[2] Their finding is consistent with ours by and large and with the idea mentioned above that change in gaze is a key social cue to the viewer that could perhaps be strong enough to overcome any deficiencies in attention toward faces that persons with autism might have.

New et al. (2009) also used the change blindness paradigm to study social attention in children with and without ASD and in non-clinical adults. Stimuli were animate (animals and people) or inanimate (plants and artifacts) objects that changed in alternate presentations of the same naturalistic scene. The study found that individuals with ASD, like their TD counterparts, were faster and more accurate at detecting changes in animate objects than inanimate ones. The New et al. study showed intact categorical prioritization of animacy in autism, a finding that points to the importance of investigating a wide array of specific social cues to see if they all stand or fall together. Our work does just that: We studied social attention in children with ASD under a variety of conditions—attention directed to the change, attention directed away from the change, attention to objects connected to persons in the scene, attention to the face of a person in the scene—and in no case was an impairment observed in the group with ASD.

Burack et al. (2009) also studied attention: They compared the abilities of children with and without autism to detect change in photographs and drawings of objects and found no difference. The authors further found that detection failures decreased weakly but significantly with increasing developmental level in TD children, but not for children with ASD. In contrast, our study was on *social* attention, and yet the findings had remarkable parallels. Children with autism exhibited similar attentional preferences for social cues in the environment as did typically developing children; performance improved more steeply with chronological and mental age for TD children than for children with autism. What was most intriguing was that the detection of change in facial expression improved marginally ($0.05 < p < 0.1$) with age for TD children but not for children with autism, which is consistent with past claims that persons with autism have insufficient face orienting and atypical face processing (Mars et al. 1998; Osterling and Dawson 1994; Osterling et al. 2002; Wimpory et al. 2000). While it is tempting to believe a finding that is in line with the general narrative in the field, it needs to be tempered by the realization that the rate of improvement with age on face expression, or for that matter, any other change type that we investigated, did not statistically differ between the two groups of children (it is notable that the Burack et al. study did not report a similar statistical comparison) *and* by the concern that a similar trend was not observed when performance on the facial expression change condition was correlated with mental age, a proxy for developmental level.

The lack of a difference between children with and without autism in detecting change across a range of image classes can be understood in the context of the stark differences observed between children and adults on the very same images. Our study suggests that deficits in social attention to certain types of social cues in the scene (i.e., facial expression) could be one source for the social shortcoming observed in children. In light of the fact that

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[2] More sensitive measurements of eye movements and scan patterns did find some subtle problems relating to social attention in young adults with autism (Fletcher-Watson et al. 2009).

the same task failed to uncover a similar difference between children with autism versus without, the findings appear to contradict the idea that the social impairment that characterizes autism can be attributed to low-level differences in social perception and attention, and instead are consistent with the idea that non-perceptual and non-attentional reasons (e.g., social stimuli are less rewarding, the stimulus–response relationship to social stimuli is too complex, etc.) underlies the profound deficit in social processing and interaction in children with autism.

There could be a number of explanations for our negative findings. Our ASD sample was somewhat heterogeneous in terms of diagnosis (6 PDD-NOS, 4 Asp. in a sample of 22 children with ASD), but also in terms of age (age range: 6 years, 10 months–15 years, 6 months). Restricting our samples to a narrower age range might have resulted in a different outcome. Additionally, both our groups were intellectually able. It is possible that comparisons between less able individuals with and without ASD could reveal differences not observed in this study. Alternatively, overall task difficulty could be involved. It was difficult to detect change on our images, as evidenced by the significantly lower change detection performance of children compared with adults and the modest d's of even the adults (overall mean ± SEM. $d' = 1.79 \pm 0.16$, range of mean d's across the six conditions was 1.33–2.50). The enhanced difficulty reduced overall performance, which may have obscured differences between the two sub-groups of children. If so, an easier change detection task might uncover latent differences between children with and without autism. Finally, one must also consider the possibility that change detection with static scenes may be unsuitable for tapping social processes in the autistic brain—it is possible that the differences in social processing that are characteristic of autism are most evident when the person with autism is viewing or participating in a dynamic social scene, rather than when passively viewing a static scene, as is the case here. These possibilities should be investigated in detail and with eye position monitoring before reaching a more definitive conclusion.

Conclusions

Differences in the ability of human beings to detect changes that vary according to social content are potentially interesting and informative (Fox et al. 2000; Langton and Bruce 2000; Langton et al. 2006; Ro et al. 2001), particularly in persons whose ability to apprehend social information is impaired. The present study found a remarkable degree of consistency in the performance of the various sub-groups of participants as a function of change type, suggesting that the types of social cues present in the different change types are just as powerful for intellectually able children and adolescents with ASD as for those without ASD. An important factor may be that in the change detection task, participants are explicitly instructed to search for a change; hence, compared with un-instructed visual exploration, in this situation persons with ASD may be more likely to attend to socially relevant cues in ways characteristic of typical persons. This possibility should be examined in future research.

Our finding of a specific set of differences in change detection between adults and children suggests that certain aspects of visual search continue to develop past youth. This result differs from earlier findings that adults and children perform similarly on change detection tasks. The difference appears to lie in a specific aspect of attentional performance in children as compared to adults as revealed by our study: Children may rely more on social cues as compared to adults, so much so that they are less attentive to other kinds of cues in the environment in the presence of social cues. It would be interesting to examine in future research how and when this tendency develops into the adult pattern of visual attention in persons with and without autism.

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References

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*(4), 433–436.

Burack, J. A., Joseph, S., Russo, N., Shore, D. I., Porporino, M., & Enns, J. T. (2009). Change detection in naturalistic pictures among children with autism. *Journal of Autism and Developmental Disorders, 39*(3), 471–479.

Fletcher-Watson, S., Leekam, S. R., Turner, M. A., & Moxon, L. (2006). Do people with autistic spectrum disorder show normal selection for attention? Evidence from change blindness. *British Journal of Psychology, 97*(Pt 4), 537–554.

Fletcher-Watson, S., Leekam, S. R., Findlay, J. M., & Stanton, E. C. (2008). Brief report: Young adults with autism spectrum disorder show normal attention to eye-gaze information-evidence from a new change blindness paradigm. *Journal of Autism and Developmental Disorders, 38*(9), 1785–1790.

Fletcher-Watson, S., Collis, J. M., Findlay, J. M., & Leekam, S. R. (2009a). The development of change blindness: Children's attentional priorities whilst viewing naturalistic scenes. *Developmental Science, 12*(3), 438–445.

Fletcher-Watson, S., Leekam, S. R., Benson, V., Frank, M. C., & Findlay, J. M. (2009b). Eye-movements reveal attention to social information in autism spectrum disorder. *Neuropsychologia, 47*(1), 248–257.

Fox, E., Lester, V., Russo, R., Bowles, R. J., Pichler, A., & Dutton, K. (2000). Facial expressions of emotion: Are angry faces detected more efficiently? *Cognition & Emotion, 14*(1), 61–92.

Jones, W., Carr, K., & Klin, A. (2008). Absence of preferential looking to the eyes of approaching adults predicts level of social disability in 2-year-old toddlers with autism spectrum disorder. *Archives of General Psychiatry, 65*(8), 946–954.

Kikuchi, Y., Senju, A., Tojo, Y., Osanai, H., & Hasegawa, T. (2009). Faces do not capture special attention in children with autism spectrum disorder: A change blindness study. *Child Development, 80*(5), 1421–1433.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry, 59*(9), 809–816.

Langton, S. R., & Bruce, V. (2000). You must see the point: Automatic processing of cues to the direction of social attention. *Journal of Experimental Psychology: Human Perception and Performance, 26*(2), 747–757.

Langton, S. R., O'Donnell, C., Riby, D. M., & Ballantyne, C. J. (2006). Gaze cues influence the allocation of attention in natural scene viewing. *Quarterly Journal of Experimental Psychology, 59*(12), 2056–2064.

Loth, E., Carlos Gomez, J., & Happe, F. (2008). Detecting changes in naturalistic scenes: Contextual inconsistency does not influence spontaneous attention in high-functioning people with autism spectrum disorder. *Autism Research, 1*(3), 179–188.

Loveland, K. A., & Landry, S. H. (1986). Joint attention and language in autism and developmental language delay. *Journal of Autism and Developmental Disorders, 16*(3), 335–349.

Mars, A. E., Mauk, J. E., & Dowrick, P. W. (1998). Symptoms of pervasive developmental disorders as observed in prediagnostic home videos of infants and toddlers. *Journal of Pediatrics, 132*((3 Pt 1)), 500–504.

Mumme, D. L., Fernald, A., & Herrera, C. (1996). Infants' responses to facial and vocal emotional signals in a social referencing paradigm. *Child Development, 67*(6), 3219–3237.

Mundy, P., Sigman, M., Ungerer, J., & Sherman, T. (1986). Defining the social deficits of autism: The contribution of non-verbal communication measures. *Journal of Child Psychology and Psychiatry, 27*(5), 657–669.

New, J. J., Schultz, R. T., Wolf, J., Niehaus, J. L., Klin, A., German, T. C., et al. (2009). The scope of social attention deficits in autism: Prioritized orienting to people and animals in static natural scenes. *Neuropsychologia, 48*(1), 51–59.

O'Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change-blindness as a result of 'mudsplashes'. *Nature, 398*(6722), 34.

Osterling, J., & Dawson, G. (1994). Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders, 24*(3), 247–257.

Osterling, J. A., Dawson, G., & Munson, J. A. (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Developmental Psychopathology, 14*(2), 239–251.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437–442.

Rensink, R. A. (2000). Seeing, sensing, and scrutinizing. *Vision Research, 40*(10–12), 1469–1487.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology, 53*, 245–277.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8*, 368–373.

Ro, T., Russell, C., & Lavie, N. (2001). Changing faces: A detection advantage in the flicker paradigm. *Psychological Science, 12*(1), 94–99.

Shore, D. I., Burack, J. A., Miller, D., Joseph, S., & Enns, J. T. (2006). The development of change detection. *Developmental Science, 9*(5), 490–497.

Simons, D. J., & Rensink, R. A. (2005). Change blindness: Past, present, and future. *Trends in Cognitive Sciences, 9*(1), 16–20.

Tomasello, M. (1995). Joint attention as social cognition. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 103–130). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Townsend, J. T., & Ashby, F. G. (1983). *Stochastic modelling of elementary psychological processes*. New York: Cambridge University Press.

Underwood, G., & Foulsham, T. (2006). Visual saliency and semantic incongruency influence eye movements when inspecting pictures. *Quarterly Journal of Experimental Psychology (Colchester), 59*(11), 1931–1949.

Walden, T. A., & Ogan, T. A. (1988). The development of social referencing. *Child Development, 59*(5), 1230–1240.

Wimpory, D. C., Hobson, R. P., Williams, J. M., & Nash, S. (2000). Are infants with autism socially engaged? A study of recent retrospective parental reports. *Journal of Autism and Developmental Disorders, 30*(6), 525–536.