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Eyetracking of social preference choices reveals normal but faster processing in autism

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Abstract

People with Autism Spectrum Disorder (ASD) have been reported to show atypical attention and eva luative processing, in particular for social stimuli such as faces. The usual measure in these studies is an explicit, subjective judgment, which is the culmination of complex-temporally extended processes that are not typically dissected in detail. Here we addressed a neglected aspect of social decision-making in order to gain further insight into the underlying mechanisms: the temporal evolution of the choice. We investigated this issue by quantifying the alternating patterns of gaze onto faces, as well as nonsocial stimuli, while subjects had to decide which of the two stimuli they preferred. Surprisingly, the temporal profile of fixations relating to choice (the so-called "gaze cascade") was entirely normal in ASD, as were the eventual preference choices. Despite these similarities, we found two key abnormalities: people with ASD made choices more rapidly than did control subjects across the board, and their reaction times for social preference judgments were insensitive to choice difficulty. We suggest that ASD features an altered decision-making process when basing choice on social preferences. One hypothesis motivated by these data is that a choice criterion is reached in ASD regardless of the discriminability of the options.

Keywords

Autism; Social; Eye-tracking; Gaze bias; Reaction time; Decision-making

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Author contributions

All authors contributed to the study design. Testing and data collection were performed by A. Gharib and D. Mier. A. Gharib performed the data analysis and interpretation under the supervision of S. Shimojo and A. Adolphs. A. Gharib drafted the manuscript and R. Adolphs, S. Shimojo, and D. Mier provided revisions. All authors approved the final version of the manuscript for submission.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http:dx.doi.org/10.1016/j.neuropsychologia.2015.04.027.

1. Introduction

Autism Spectrum Disorder (ASD) is a pervasive developmental disorder characterized by impairments in social and cognitive processing. One of the core diagnostic criteria for this disorder is a deficit in social communication and social interaction (DSM-V), which presents in real-life interactions as an inattention to faces and reduced eye contact, in addition to more complex social deficits such as difficulty recognizing emotional expressions and relating to others. Several hypotheses propose that motivational or attentional social deficits in early life could disrupt a critical phase in normal brain development, during which early social orienting typically lays the framework for more complex social and cognitive processes to develop later in life (Chevallier et al., 2012; Dawson et al., 2002, 2004). In people with ASD, these early onset motivational deficits may cause reduced social orienting and learning from a young age, resulting in decreased attending to social stimuli, which further disrupts normal development of cognitive processes related to social perception (Mundy and Neal, 2000).

A large number of studies examining these social impairments have found a reduced attentional bias towards faces in ASD. When viewing complex social scenes, people with autism make fewer initial fixations to the person and to the face within a scene relative to controls, indicating there is reduced spontaneous attentional capture by social stimuli (Fletcher-Watson et al., 2009). Similarly, in a selective attention task for which controls are unable to ignore irrelevant faces, people with ASD were found to be undistracted, leading the authors to suggest that a deficit in the automatic processing of faces may underlie the diminished attentional bias for faces (Remington et al., 2012).

In addition to the reduced saliency of faces for people with autism, many studies have found that when people with ASD do fixate on faces, the pattern of visual behavior with respect to facial features differs from neurotypical viewing behavior. The exact nature of these differences, however, is far from clear. Some studies report reduced gaze to the eyes and increased reliance on information in the mouth region (Klin et al., 2002; Spezio et al., 2007) while other studies that similarly report reduced gaze to the eyes find little difference in gaze to the mouth region (Corden et al., 2008; Dalton et al., 2005). Pelphrey et al. (2002) even reported reduced fixation time to all socially-salient regions of the face, including the eyes, nose, and mouth, and increased gaze to non-feature regions of the face. The variable results have been attributed to a number of factors, including experimental differences in stimulus type (e.g., static/dynamic, computer-generated/real faces) and task demand (e.g., emotion judgment, gaze direction, etc.). However, a growing number of studies also propose that discrepant results arise, in part, due to the use of compensatory mechanisms or atypical processing strategies during certain types of face perception tasks, particularly by individuals who are high-functioning (Harms et al., 2010; Joseph and Tanaka, 2003; Rice et al., 2012; Rutherford and McIntosh, 2006).

Abnormal gaze behavior in ASD is often accompanied by difficulties evaluating social information conveyed by faces, such as recognizing emotional expressions. Again, the findings are inconsistent, but some behavioral studies have found impaired recognition of basic emotions in ASD: compared to their neurotypical counterparts, people with autism are slower and less accurate in identifying certain negative emotional expressions such as anger, fear, and sadness (Ashwin et al., 2006; Bal et al., 2009; Wallace et al., 2008), though basic emotion recognition might still be preserved in high-functioning individuals (Castelli, 2005). There is stronger evidence, however, in support of impairments recognizing complex emotions, such as jealousy and trustworthiness, and making higher-level social judgments from faces that involve attributions of mental state (Adolphs et al., 2001; Baron-Cohen et al., 1997). Moreover, deficits in the ability to recognize facial expressions of emotions such as fear (Pelphrey et al., 2002) and sadness by people with ASD (Corden et al., 2008) are correlated with abnormal gaze to central features of the face, and particularly the eyes.

Two highly relevant aspects of social processing have, however, not been much investigated: our preference decisions among social stimuli, and the temporal evolution of preference-based choices. First, most of the research on face processing to date focuses on emotion recognition or face perception in general, and few studies have investigated how these factors can influence our preferences of faces. Thus far, much of the research examining visual behavior in ASD has focused on atypical visual behavior and the nature of these impairments specifically in the context of objective decision-making, such as correctly identifying emotional expressions. What is unknown, however, is whether these reported deficits also extend to making more subjective decisions, such as those involving face preference or attractiveness, which are just as relevant to social functioning, perhaps even more so. Secondly, it remains unknown how abnormal social judgments about faces might arise—what is the timecourse and possible underlying mechanism as atypical choices unfold?

Previous studies in typically developed individuals have investigated the cognitive processes involved in making preference choices. One class of models is known as drift diffusion models (DDM) and was initially proposed by Ratcliff and colleagues to describe two-choice decision processes (Ratcliff, 1978; Ratcliff and McKoon, 2008). These models assume that evidence for each alternative is accumulated and integrated over time until a decision threshold is reached. More recent studies have shown that integrating eyetracking data as an additional parameter in the DDM results in a model that better predicts choice and possibly reaction times (Krajbich et al., 2010).

Similar in form to the drift diffusion models is the gaze cascade phenomenon proposed by Shimojo et al. (2003), emphasizing the behavioral dynamics of preference choice. In their model, it is proposed that preference and gaze mutually interact in a positive feedback loop to produce an effect known as a “gaze cascade”. Given a choice between two stimuli, individuals are initially just as likely to inspect one image in the pair as the other. However, in the few seconds before a preference decision is made, an increasing gaze bias occurs toward the eventually-chosen stimulus. Shimojo and colleagues propose that in the moments before this decision is made, a positive feedback pathway is engaged in which the gaze bias towards the to-be-chosen image leads to increased preference, which in turn increases gaze bias further, and so on, until the preference signal surpasses threshold leading to a behavioral decision. Thus in this model, gaze orienting is intrinsically linked to and necessary for decision-making and vice versa. Indeed, further evidence supporting the reciprocal effect of gaze on preference formation is demonstrated in experiment 2 of the same paper and a follow-up study using fMRI (Ito et al., 2014). In both studies, one face in a pair is presented on screen for a longer duration than the other face. After several repetitions, participants report a preference bias for the longer-presented face, indicating that manipulation of gaze can directly influence preference decisions. While the gaze cascade effect has been observed in other studies examining preference choice (Noguchi and Stewart, 2014; Simion and Shimojo, 2006), the effect may also extend to other types of visual decision-making tasks (Fiedler, 2012; Glaholt and Reingold, 2009; Wiener et al., 2011).

Given that the literature suggests atypical viewing behavior in ASD is accompanied by deficits in processing social information, the current study sought to examine the influence of gaze on preference choice in autism and, specifically, whether eye movements reveal a fundamentally different evaluation process in ASD. Eye-tracking was used to investigate gaze behavior in adults with high-functioning autism while they made preference decisions amongst pairs of social and non-social stimuli. Since direct gaze can elicit atypical visual behavior in ASD, we utilized face stimuli depicting open eyes as well as closed eyes so that we could determine whether a potentially abnormal "gaze cascade" effect was caused by an avoidance of direct gaze, or rather an overall difficulty in making self-paced preference judgments for faces. Furthermore, we tested whether the typically robust gaze cascade would remain intact under time pressure by using a time restriction in one block. Consistent with evidence that individuals with ASD have difficulty evaluating and making social judgments about faces, and given evidence of reduced attention to faces and direct gaze in ASD, we predicted that the ASD group would not have a normal gaze cascade, take longer than controls to make preference choices regarding faces, and end up making unusual preference choices. To our surprise, we found an essentially typical gaze cascade, normal final preferences, and faster decision times in ASD.

2. Materials and methods

2.1. Participants

Participants were a group of 12 high-functioning subjects with a DSM-IV diagnosis of Autism Spectrum Disorder (M_{age}=35.4 years, *SD*=12.8, age range=22–58; Females=3). Sample size was determined by participant availability. Diagnosis was confirmed by ADOS (Autism Diagnostic Observation Schedule; Lord et al., 2000) and ADI-R (Autism Diagnostic Interview-Revised; Lord et al., 1994) or SCQ (Social Communication Questionnaire; Rutter et al., 2003). The comparison group consisted of 12 healthy controls (M_{age}=33.3 years, *SD*=11.9, age range=20 59; Females=1), group-matched for age, gender, and IQ, with no family history of psychiatric illness. Table 1 summarizes demographic and diagnostic information for participants.

Independent samples *t*-tests showed that the groups were not significantly different in terms of age ($t(22)=0.44$, $p=0.685$), gender ($p=0.590$, 2-sided Fisher's Exact Test) and IQ ($t(22)=-0.87$, $p=0.392$), as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). All participants gave written informed consent to participate under a protocol approved by the Institutional Review Board of the California Institute of Technology.

2.2. Stimuli and apparatus

Stimuli consisted of pairs of social stimuli (computer-generated human faces) or pairs of non-social stimuli (nature scenes sourced from a google image search for “desert” and “mountain”). Face images, generated using Facegen (Singular Inversions, Vancouver, Canada), were front-facing with neutral emotional expression and direct eye contact.

To control for gaze bias due to differences in baseline attractiveness of the stimuli, all images were drawn from a larger set of face and nature scene stimuli pre-rated for attractiveness by a separate group of non-autistic participants on a scale of 1 (very unattractive) to 7 (very attractive) (n=20, Females=8; M_{age}=28.2 years, SD=7.5). In accordance with the original gaze cascade study, images were then selected and paired such that half the pairs in each block had images that were equal in attractiveness pre-ratings (“high difficulty” trials) and the other half had a difference of 1.5 points (“low difficulty” trials). Each image pair was presented in randomized order once per block, and the location of each image in a pair was left-right randomized. The two Open Eyes blocks and the Roundness block (see Fig. 1) used the same set of faces. For a further condition with a stricter time restriction, we created a novel set of face stimuli from the images that had been pre-rated by the same participants, in order to eliminate memory effects. Image pairs in the Timed condition had the same mix of “high difficulty” and “low difficulty” trials as the untimed conditions.

Images were presented on a 21″ CRT monitor with a refresh rate of 100 Hz and pixel resolution of 1152×864. The stimuli in each test pair were presented simultaneously on the left and right side of the screen. At a viewing distance of approximately 57 cm, each stimulus pair had an overall size of 36.2 (width)×14.4 (height) degrees of visual angle.

Stimuli were presented using Matlab (Mathworks, Natick, MA), the Psychophysics toolbox (Brainard, 1997), and the Eyelink toolbox (Cornelissen et al., 2002). Gaze data was collected using a head-mounted Eyelink II eye-tracking system (SR Research, Osgoode, Canada). Corneal and pupil reflection were recorded at a sampling rate of 250 Hz. At the beginning of each block, a 9-point calibration was performed. Each trial began by requiring subjects to fixate on a central drift correction dot. After the eye-tracker registered a successful fixation, participants pressed the space bar to start the trial.

2.3. Procedure

Subjects performed various 2-alternative forced-choice (2AFC) tasks while eye-gaze was tracked (see Fig. 1). Subjects inspected a pair of simultaneously presented stimuli, then made the 2AFC choice by pushing either the left or right button. In advance of the experiment, subjects completed 20 trials with simultaneously-presented geometrical shapes in which they had to indicate which of the two was a triangle. This task was implemented to check for basic motor response time differences between groups.

Experimental design consisted of five blocked conditions where either the stimulus or task instruction was varied (see Fig. 1 for summary of experimental conditions and sample stimuli). In three of the blocks, participants made self-paced preference decisions, viewing either faces with open eyes (Open Eyes), faces with closed eyes (Closed Eyes), or nature scenes (Nature Scenes), reporting which face (or nature scene) they liked the most. In another block, participants viewed open-eyed faces but instead made objective decisions as to which face was rounder (Roundness), again with no time limit. In the fifth block, participants viewed open-eyed faces and made preference decisions, but were instructed to try to make the decision in under 1.5 s. (Timed). All blocks consisted of 40 trials, with the exception of our main condition of interest, Open Eyes, which consisted of 80 trials. Block order was counter-balanced across subjects.

Lastly, we selected a subset of the images presented in the experiment (13-14% of all images) that had been given low, average, and high attractiveness pre-ratings and had all participants rate this subset for attractiveness on a scale of 1 (very unattractive) to 7 (very attractive).

2.4. Analyses

Data were analyzed using custom scripts written in Matlab. In the four preference decision conditions (Open Eyes, Closed Eyes, Timed, and Nature Scenes), high difficulty trials were compared to low difficulty trials (as defined above in Section 2.2). For the objective Roundness condition, we defined difficulty by calculating a height to width ratio for each face, and then ranking the stimulus pairs according to face ratio differences. The 20 trials with the smallest differences were defined as high difficulty; the largest 20 differences, low difficulty.

We used two analysis methods to examine the level of consistency in preference choices between the two groups. First, we calculated a between-group correlation of the proportion of subjects in each group that chose a given image in each pair, collapsing across the two difficulty levels. Second, we examined whether both groups' preference choices in the low difficulty trials agreed with the attractiveness ratings made by the pre-rating group. We limited this second analysis to low difficulty trials because only low difficulty trials had an objectively correct (i.e., higher-rated) image for the preference tasks, allowing us to define accuracy. A binary logistic regression analysis was carried for each subject and each block, regressing the dependent variable of preference decision against the consensus-preferred image as defined by the pre-rating group. This resulted in a set of beta weights representing the degree to which the higher-rated image (or rounder image in the case of the Roundness condition) predicted a subject's preference choices in a given block. We compared beta weights between groups using independent samples *t*-tests.

To compare our gaze results to those obtained in the original gaze cascade study (Shimojo et al., 2003), a similar post-experiment analysis was conducted. Eye tracking data from all trials in a condition were aligned to the time of decision (i.e., button press). For each eye-tracking point from decision time going back to 1 s before decision time, a “true” value was assigned when gaze was on the to-be-chosen stimulus, and a “false” value when gaze was on the unchosen stimulus. Points outside either stimulus were treated as “not a number.” The ratio of “true” to “false” values for each time-point was averaged across trials and subjects in each group to obtain the likelihood of gaze bias toward the chosen stimulus at each time point. The data from the ASD group and from the control group were then each fit with a four-parameter sigmoid regression curve for each condition, with the four parameters representing the following: (1) bottom plateau - baseline comparison probability between the two stimuli, (2) top plateau - gaze bias at which the participant made the conscious behavioral choice, (3 & 4) point of inflection and slope at point of inflection - timescale indicating the quickness of the decision. Lastly, 95% confidence intervals were calculated for the four parameter estimates. Note that because each time point is averaged over multiple trials to interpolate the sigmoid function, the fit describes the time course of gaze probability at a given time point ahead of decision time (i.e. button press) rather than trial-by-trial gaze behavior.

To test whether the sigmoid parameters differed significantly between groups, non-parametric permutation tests were used, with the difference between control and autism group parameter estimates as test metrics. We reshuffled the group labels (ASD, control) to create 10,000 synthetic data sets, calculating the sigmoid fit parameters for each. The empirical distribution of the parameters was used to calculate the probability of seeing between group parameter differences greater than those observed in the present study. Parameter estimates were considered significantly different between groups if the difference between estimates was in the top 2.5% or bottom 2.5% of the permutation distribution for that parameter (most extreme positive or negative differences).

Reaction times (RTs) were log-transformed prior to statistical analysis to rectify the positively skewed distribution. Raw values are reported in the text and figures. Trials were excluded if reaction times were greater than 3 *SD* outside the group mean, or if no valid button press was registered (<1% of the data).

Baseline reaction times in the preliminary geometrical shape recognition task were compared between groups with a one-way ANOVA. For the five experimental conditions, RTs were first analyzed with a 2×5 repeated-measures ANOVA, with a between-subjects factor of group (ASD, control) and within-subjects factor of condition (Open Eyes, Closed Eyes, Timed, Roundness, and Nature Scenes). For the second level of analysis (examining the effect of decision difficulty on RTs), four (2×2×2) repeated-measures ANOVAs were carried out comparing the Open Eyes condition to each of the other four conditions, with a between-subjects factor of group and an additional two-level factor of decision difficulty (high difficulty, low difficulty). In RT analyses with decision difficulty as a factor, we analyzed all trials belonging to that difficulty level, regardless of eventual preference choice. Post-hoc tests were conducted when appropriate (2-tailed independent sample *t*-test, unless otherwise indicated). Degrees of freedom were Greenhouse-Geisser corrected when violations of sphericity occurred. Mean fixation durations, fixation rates, and inverse efficiency scores were each analyzed with a 2×5 repeated-measures ANOVA, with a between-subjects factor of group and within-subjects factor of condition.

3. Results

3.1. Fixation behavior

A preliminary analysis comparing mean fixation durations and fixation rates between groups revealed no significant interactions (*p*s>0.663) or main effects of group (*p*s>0.351). Results are summarized in Supplementary Fig. S1.

3.2. Preference choices

A correlation analysis was conducted to assess the agreement between preference choices in the ASD and control groups (see Table 2). There was a significant positive correlation between preference choices made by the two groups in all five conditions, four of which survived correction for multiple comparisons.

To examine the degree to which each groups' preference choices agreed with the attractiveness ratings made by the pre-rating group, a binary logistic regression analysis was carried out for the low difficulty trials, regressing the dependent variable of preference decision against the consensus-preferred image, and *t*-tests were performed on the resulting beta weights (see Table 3). None of the group differences in beta weights were significant.

3.3. Gaze cascade effect

The likelihood that an observer's gaze was on the to-be-chosen picture was plotted against time before decision (see Fig. 2). The results showed that the gaze cascade effect was present for both groups in all five conditions. For each group, a four-parameter sigmoid function (parameters: bottom plateau, top plateau, point of inflection, and slope at point of inflection) fit the likelihood curves well in all five conditions.

Based on non-parametric tests using 10,000 random group assignments, we calculated the empirical probability of seeing parameter differences greater than those observed in the present study. To test whether the sigmoid parameters differed significantly between groups, parameter estimates for the control group were subtracted from parameter estimates for the ASD group and compared against the probability distribution from permutations testing (see Section 2 for details). None of the parameter differences between groups in the five conditions reached p=0.05 significance, even when a correction for multiple comparisons was not applied (see Supplementary Table S1).

3.4. Reaction times

A one-way ANOVA comparing baseline reaction time in the preliminary geometrical shape recognition task confirmed the ASD and control groups did not differ in basic motor response times, $F(1,22)=0.02$, $p=0.882$.

Reaction times for the experimental conditions were first analyzed using a 2×5 ANOVA comparing all five experimental conditions (see Fig. 3). Compared to controls, the ASD group had faster reaction times overall, reflected in a near-significant main effect of group, $F(1,22)=4.23$, $p=0.052$, $\eta^2=0.16$. Post-hoc comparisons revealed significant group differences in the Closed Eyes condition (ASD: $M=2.16$, $SE=0.32$; controls: $M=3.13$, $SE=0.30$), $t(22)=-2.31$, $p=0.030$, and Timed condition (ASD: $M=1.22$, $SE=0.14$; controls: $M=1.62$, $SE=0.14$), $t(22)=-2.13$, $p=0.045$, and a trend-level group difference in the Open Eyes condition (ASD: $M=2.04$, $SE=0.20$; controls: $M=2.77$, $SE=0.27$), $t(22)=-1.93$, $p=0.067$. Differences in RTs in the Roundness and Nature Scenes conditions were not significant ($p=0.179$ and $p=0.400$, respectively).

To investigate RT differences between groups in the Open Eyes condition in comparison to the other conditions, a (2×2×2) repeated-measures ANOVA (factors: group×condition×difficulty) was calculated each time comparing the Open Eyes condition to each of the other four experimental conditions, with a between-subjects factor of group (ASD, control) and a two-level factor of decision difficulty (high difficulty, low difficulty). Means and standard errors for RTs in the individual conditions are shown in Table 4.

3.4.1. Face preference: Open Eyes vs. Closed Eyes—The ANOVA comparing the effect of Closed Eyes vs. Open Eyes on RTs indicated there was a significant main effect of group, $F(1,22)=4.93$, $p=0.037$, $\eta^2=0.183$, for faster RTs in the ASD group compared to the control group. None of the other main effects or interactions reached significance (all ps>0.146).

3.4.2. Face preference: Timed vs. untimed—The ANOVA comparing the Timed condition to the self-paced Open Eyes condition revealed a significant interaction between group and difficulty on RTs, $F(1,22)=6.12$, $p=0.022$, $\eta^2=0.218$, as well as a trend-level three-way interaction, $F(1,22)=3.69$, $p=0.068$, $\eta^2=0.144$. Paired-samples t-tests indicated trend-level differences in the Timed condition for controls (controls: high difficulty: $M=1.63$, $SE=0.14$; low difficulty: $M=1.60$, $SE=0.15$), $t(11)=-1.75$, $p=0.109$, but not for the ASD group (ASD: high difficulty: $M=1.23$, $SE=0.14$; low difficulty: $M=1.21$, $SE=0.14$), $t(11)=-0.73$, $p=0.484$. There was also a significant group effect for faster RTs in the ASD group compared to controls, $F(1,22)=6.59$, $p=0.018$, $\eta^2=0.230$.

3.4.3. Face preference vs. face roundedness—The ANOVA comparing the Roundness condition to Open Eyes revealed a significant interaction between condition and difficulty on RTs, $F(1,22)=15.56$, $p=0.001$, $\eta^2=0.414$, as well as a trend-level group effect, $F(1,22)=2.99$, $p=0.098$, $\eta^2=0.120$. Paired-samples t-tests indicated both groups took significantly longer for high difficulty compared to low difficulty decisions in the Roundness task (controls: high difficulty: $M=2.58$, $SE=0.24$; low difficulty: $M=2.01$, $SE=0.18$), $t(11)=-3.41$, $p=0.006$, (ASD: high difficulty: $M=2.08$, $SE=0.32$; low difficulty: $M=1.74$, $SE=0.25$), $t(11)=-2.66$, $p=0.022$.

3.4.4. Social vs. non social preference—The ANOVA comparing the Nature Scenes condition to Open Eyes revealed a significant interaction between group and difficulty, $F(1,22)=7.01$, $p=0.015$, $\eta^2=0.242$, indicating that decision difficulty had a different effect on RTs in the control group than on those in the ASD group. There was also a main effect of difficulty, $F(1,22)=4.53$, $p=0.045$, $\eta^2=0.171$. None of the other main effects or interactions reached significance (all ps>0.177).

To examine the effect of decision difficulty on RTs in each group, within-group comparisons were performed on pooled data from the Nature Scenes and Open Eyes conditions. Paired-samples t-tests showed the control group took longer to make decisions in high difficulty trials compared to low difficulty trials (high difficulty: $M=2.85$, $SE=0.29$; low difficulty: $M=2.70$, $SE=0.27$), $t(11)=-2.97$, $p=0.013$, whereas there was not a significant effect of difficulty on RTs in the ASD group (high difficulty: $M=2.21$, $SE=0.26$; low difficulty: $M=2.22$, $SE=0.26$), $t(11)=0.32$, $p=0.757$.

3.4.5. Inverse efficiency scores—Lastly, we checked for a speed-accuracy tradeoff by analyzing RT and accuracy together, computing inverse efficiency scores (i.e., reaction time divided by accuracy) for each participant and condition in the low difficulty trials. A 2×5 ANOVA with a between-subjects factor of group and within-subjects factor of condition indicated there was no interaction between condition and group (p=0.805) and no significant difference between groups (p=0.108).

There were no significant correlations between Autism Quotient scores (AQ) and RTs for the ASD group, nor IQ and RTs for either group.

3. Discussion

Here, we found that individuals with ASD and controls made similar preference decisions in judging the attractiveness of faces, and that they arrived at those decisions using similar sampling processes, displaying the "gaze cascade" interaction between internal preference and attention bias. Where the ASD group differed from controls was in faster decision times, and also in an insensitivity to task difficulty in the facial preference tasks. Whereas reaction times generally increased for difficult judgments in controls, the ASD group responded equally quickly when judging the attractiveness of closely matched faces.

People with ASD made similar preference choices compared to the control group. Preference choices were correlated between the two groups, and the ASD group chose the higher-rated image with generally the same frequency as controls across all conditions. Additionally, attractiveness ratings for the post-rated subset of stimuli were strongly correlated between groups (see Supplementary Table S2), which strongly suggests the initial ratings used to define difficulty level are also appropriate for the ASD group. In other words, face pairs that were defined as equally-attractive face pairs based on non-autistic pre-ratings were also likely to be considered equally attractive by ASD subjects.

With respect to visual behavior, when we examined mean fixation durations and mean fixation rates, no significant group differences were detected in the details of the gaze pattern. Moreover, both the ASD and control groups replicated the gaze cascade effect observed in the original paper (Shimojo et al., 2003). That is, the feedback loop linking visual orienting with preference decisions is intact in ASD, which was not expected given the literature on atypical gaze to faces in autism. This indicates that the ASD group used similar preference decision-making processes compared to neurotypicals even with social stimuli. Lastly, comparison of the four parameters of the gaze cascade curves using permutations testing revealed no significant differences between the groups in any of the conditions. Thus, the process of visual orienting to the preferred stimulus and the temporal profile of fixations leading up to the choice exists in the ASD group independent of stimulus and decision type.

Despite the lack of differences in decision outcomes and orienting behavior, the ASD group was significantly faster in making preference decisions overall. This effect may seem incompatible with the lack of difference in gaze cascade fits, but the gaze cascade model is time-locked to the final response (decision), not the onset of the stimulus, thus the model is relatively insensitive to variances in total performance time (RT), as well as the initial response (gaze) to the stimulus. The source of the speeded responses is unclear, but the data do contain some suggestive clues. First, the lack of significant group differences in the gaze cascade model fits strongly suggests that the processing advantage is not due to an abbreviated or otherwise abnormal feedback loop linking foveation and eventual preference. Second, post-hoc tests indicated that the main reaction time advantage stemmed mainly from faster response times in preference decisions for faces, as opposed to the objective face decisions or the decisions for natural scenes, and that there was a complete lack of a reaction time advantage in the geometrical shape discrimination. This suggests that the mechanism lies in a higher-level component of preferential decision-making for faces, rather than in low-level motor, visual or executive factors.

Our other analyses of fixation behavior did not point to a particular source of the speeded responses. However, we did find an isolated effect of shorter latencies to first face fixation in the Timed condition for ASD (see Supplementary Fig. S1C). A future study focusing on this high-pressure condition may be able to uncover more informative results regarding the early phases of preference formation.

Given the faster reaction times in ASD, we also examined whether the difficulty of the decision affects reaction times. Interestingly, the ASD group was insensitive to the difficulty of the decision, whereas controls had slower reaction times when images were similarly rated, as expected. Most intriguingly, this insensitivity was strongest for face preference decisions: difficulty did increase RTs for face roundness judgments in ASD. Our failure to find any robust RT differences in the nature scenes condition may have been due to lack of statistical power. It is worth noting that even in controls there was not a strong effect of difficulty for nature scenes. Thus, RTs in the ASD group seem to be particularly insensitive to decision difficulty for social preference decisions.

We found no evidence to indicate the faster RTs were due to inattention or a random or rushed decision-making process. The ASD group's preferences were not divergent from or noisier than the control group's preferences. The strong correlation of the ASD group's choices with both the control group’s choices and the attractiveness pre-ratings from a separate non-autistic group indicates the ASD group used similar or convergent criteria to evaluate attractiveness. Finally, the lack of a group difference in inverse efficiency scores reflects that faster RTs were not accompanied by a disproportionately large decrease in accuracy in ASD (i.e., there was not a corresponding loss in performance). Thus, one possible explanation could be that a choice criterion is reached in social decisions regardless of the discriminability of the options, although the fundamental mechanism underlying the choice decision may be shared between groups. Future studies with more formal modeling approaches than the methods used here would be needed to test this hypothesis.

There is precedent for the idea that people with ASD may be faster on certain kinds of timed visual/perceptual tasks. A study by Hayashi et al. (2008) reported that children with Asperger's Syndrome scored higher than typically developing children on the Raven's Standard Progressive Matrices test (RSPM), a nonverbal intelligence test in which subjects identify the missing geometric element that completes a specific pattern. Another study using the RSPM found that while people with autism performed the test with the same accuracy as controls (Souliéres et al., 2009), their response times were significantly faster, suggesting that in certain situations visual processing was enhanced in ASD. There is also evidence to indicate people with ASD can outperform neurotypicals in tasks involving mental rotation (Souliéres et al., 2011), visual search (Jolliffe and Baron-Cohen, 1997; Keehn et al., 2008) and visual discrimination (Joseph et al., 2009). The explanations given for such results include an underlying local processing advantage, lack of engagement with stimuli allowing for more efficient processing, or perhaps fundamental differences in motivational state.

One contrast between the above results and our results is that our task is ostensibly social in nature, a domain in which people with ASD are generally thought to be at a disadvantage. There are a few related factors that could help to interpret this discrepancy. First, it is known that individuals with autism can mitigate social deficits using explicitly and implicitly guided compensatory strategies, masking social impairments in spite of atypical processing of social stimuli. The effectiveness of such explicit top-down strategies has been found in tasks involving facial discrimination and emotion recognition (Rutherford and McIntosh, 2006; Teunisse and de Gelder, 2001; Wong et al., 2008). Similarly, implicit compensatory strategies, such as prioritizing of local over configural information (Dawson et al., 2005; Rondan and Deruelle, 2007) are reported to underlie the performance advantage observed in ASD relative to controls in certain types of face perception tasks (Hobson et al., 1988; Langdell, 1978; Tantam et al., 1989). Second, it may be that the face preference task does not involve higher-level social judgments. The task regarded personal preferences, and did not require mental state inferences or social attributions regarding the face or other potential viewers, domains in which high-functioning individuals are more likely to show impairments compared to lower-level social processes that are often spared. In that sense, the task might even have been approached as a perceptual task, rather than a social one. This would be consistent with the faster RTs observed in ASD, and also the insensitivity of RTs to the relative attractiveness of the faces. Finally, it could be the case that face processing deficits in high-functioning ASD become apparent only when there are more complex attentional demands, such as in real-life situations, or when there is competing visual information, such as with dynamic stimuli. This could also occur if attentional demands become too great to sustain explicit or implicit compensatory strategies.

The current study had several limitations. First, while the use of computer-generated faces is favorable in terms of controlling for potential confounds (e.g., facial expression), social stimuli with greater ecological validity (such as photographs or dynamic stimuli) may be more likely to elicit atypical gaze behavior, particularly in individuals with high-functioning autism. Second, the difficulty factor was predefined based on ratings obtained from a separate group of non-autistic participants. Due to time limitations during the actual experiment, we obtained post-ratings for only a small portion of the stimuli that were used. While we chose images that reflected a range of attractiveness ratings, people with ASD may have different face preferences that were not captured by the stimuli presented in the post-rating set. Future directions include gathering ratings for all stimuli to be presented in the study and using these ratings to determine face pairings separately for each group, in order to eliminate the possibility that the two groups perceived task difficulty differently.

In summary, individuals with high-functioning autism have a similar gaze cascade and also made similar preference choices across the stimuli compared to neurotypicals. We can therefore conclude that in individuals with high-functioning autism, the preference formation mechanism linking gaze orienting and eventual choice is intact. With these similarities in mind however, there were two major differences between groups: reaction times in the autism group were faster compared to controls and furthermore, they were insensitive to the difficulty of the choice. Thus, more detailed analysis of task difficulty, reaction times, and even face preferences would help here, and in the future, to determine whether subjective decisions about faces systematically differ in people with ASD. Especially, it may worth paying attention to the initial phase of orienting and perceptual processing leading up to the preference decision, as discussed above. In future work, researchers might investigate the extent to which deficits in processing social information affect preference decisions using dynamic or emotional stimuli.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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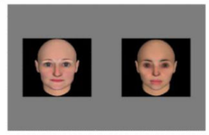
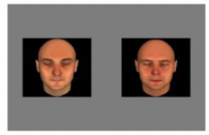
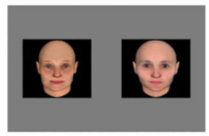
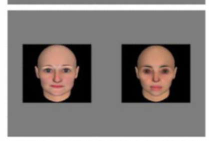
Condition Name	Stimuli Description	Example Stimuli	Time per Trial	Decision Type
Open Eyes	Faces with Open Eyes		Self-paced (2 x 40 trials)	Preference Judgment
Closed Eyes	**Faces with Closed Eyes**		Self-paced (40 trials)	Preference Judgment
Timed	Faces with Open Eyes		**1.5 seconds** (40 trials)	Preference Judgment
Roundness	Faces with Open Eyes		Self-paced (40 trials)	**Objective Judgment**
Nature Scenes	**Nature Scenes**		Self-paced (40 trials)	Preference Judgment

Fig. 1.

Summary of experimental conditions and example stimuli.

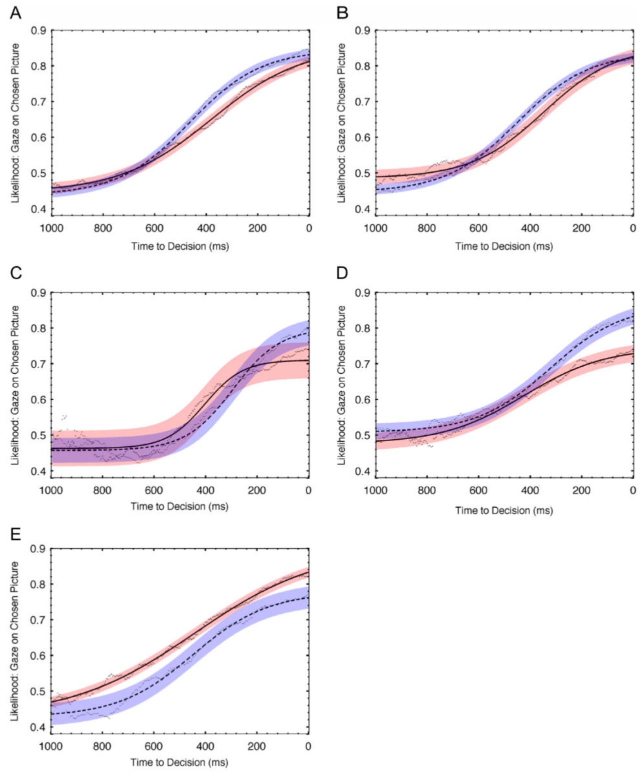


Fig. 2.

The likelihood that a participant's gaze is directed at the to-be-chosen stimulus is plotted against time to decision for the autism group (solid line) and control group (dashed line) for (A) Open Eyes, (B) Closed Eyes, (C) Timed, (D) Roundness, and (E) Nature Scenes. Dots represent raw data averaged across trials and subjects for each time point. Four-parameter sigmoids (solid and dashed lines; parameters: bottom plateau, top plateau, point of inflection, and slope at point of inflection) were fit to each likelihood curve (all R^2s>0.942). Shading denotes 95% confidence bounds of the sigmoid fit.

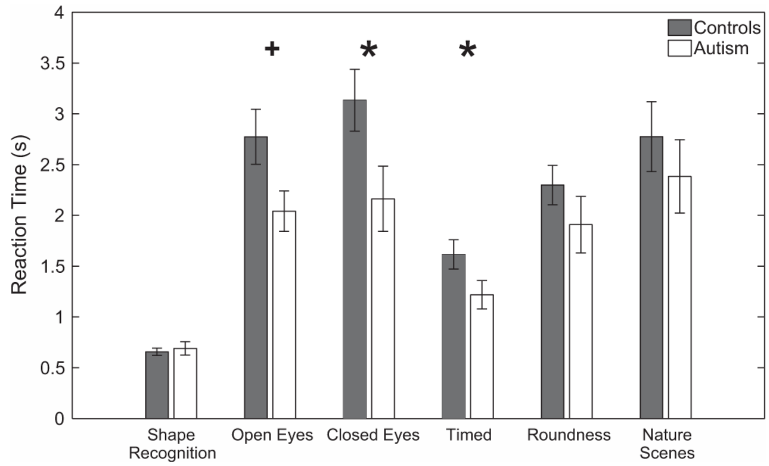


Fig. 3.

Mean reaction times for the preliminary geometrical shape recognition task and experimental conditions, for the autism (light) and control (dark) groups. Error bars denote standard error. *$p<0.05$, $^{+}$ $p<0.10$.

Table 1

Demographic and diagnostic information for participants.

	Autism group			Autism group: ADOS	
	Age	***Verbal IQ***	***Full scale IQ***	***SOC***	***COM+SOC***
1	58	118	126	7	9
2	24	118	101	7	12
3	22	102	107	14	21
4	22	101	102	13	20
5	42	80	93	14	20
6	30	111	106	11	17
7	57	119	102	8	12
8	31	127	124	7	11
9	26	89	93	7	10
10	47	109	104	7	9
11	29	117	115	14	20
12	37	135	133	9	13
Mean	35.4	110.5	108.8		
SD	12.8	15.5	12.9		
Control group					
	Age	*Verbal IQ*	*Full scale IQ*		
Mean	33.3	111.7	113.1		
SD	11.9	11.7	11.3		

Verbal IQ and full-scale IQ from the Wechsler Abbreviated Scale of Intelligence; ADOS: Autism Diagnostic Observation Schedule; SOC: social interaction subscale; COM+SOC: communication+social interaction subscales.

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Table 2

Between-group correlation of preference choices in low and high difficulty trials combined.

	Open Eyes	Closed Eyes	Timed	Roundness	Nature Scenes
Pearson's *r*	676*	445*	389	830*	618*
p Value	<0.001	0.004	0.012	<0.001	<0.001

* $p<0.01$(corrected for multiple comparisons). Note that the listed significance is uncorrected.

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Table 3

Results of the binary logistic regression model for low difficulty trials, regressing the dependent variable of preference choice against the consensus-preferred image as defined by the pre-rating group (beta weight means and standard errors, and *p* Values from 2-tailed *t*-tests).

	Open Eyes		Closed Eyes		Timed		Roundness		Nature Scenes	
	Mean β	***SE***	**Mean β**	***SE***	**Mean β**	***SE***	**Mean β**	***SE***	**Mean β**	***SE***
Controls	4.09	1.69	1.40	0.29	4.81	2.38	16.32	2.89	4.15	2.43
Autism	1.89	0.31	2.83	1.81	1.19	0.32	16.20	3.06	2.97	1.86
p Value	0.21	0.45	0.15	0.98	0.71					

Table 4

Mean reaction times in seconds (non-transformed values) and standard errors for high and low difficulty trials, and mean accuracy scores for low difficulty trials.

Condition		**Control group**				**Autism group**			
		Reaction time		**Accuracy**		**Reaction time**		**Accuracy**	
		Mean	***SE***	**Mean**	***SE***	**Mean**	***SE***	**Mean**	***SE***
Shape recognition		0.66	0.04	99.6%	0.00	0.69	0.07	100%	0.00
	Difficulty level								
Open Eyes									
	High	2.89	0.30	–	–	2.01	0.19	–	–
	Low	2.66	0.25	75.8%	0.03	2.07	0.21	70.4 %	0.03
Closed Eyes									
	High	3.20	0.35	–	–	2.18	0.33	–	–
	Low	3.07	0.27	65.1%	0.03	2.15	0.32	62.8%	0.04
Timed									
	High	1.63	0.14	–	–	1.23	0.14	–	–
	Low	1.60	0.15	59.6%	0.03	1.21	0.14	55.7%	0.03
Roundness									
	High	2.58	0.24	–	–	2.08	0.32	–	–
	Low	2.01	0.18	89.6%	0.06	1.74	0.25	92.5%	0.02
Nature Scenes									
	High	2.81	0.32	–	–	2.41	0.37	–	–
	Low	2.73	0.37	61.7%	0.04	2.36	0.35	65.4%	0.05