

**Perspective influences eye movements during real-life conversation: Mentalising about
self vs. others in autism**

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Abstract

Socio-communication is profoundly impaired among autistic individuals. Difficulties representing others' mental states have been linked to modulations of gaze and speech, which have also been shown to be impaired in autism. Despite these observed impairments in 'real-world' communicative settings, research has mostly focused on lab-based experiments, where the language is highly structured. In a pre-registered experiment, we recorded eye movements and verbal responses while adults (N=50) engaged in a real-life conversation. Conversation topic either related to the self, a familiar other, or an unfamiliar other (e.g. "Tell me who is your/your mother's/Marina's favourite celebrity and why?"). Results replicated previous work, showing reduced attention to socially-relevant information among autistic participants (i.e. less time looking at the experimenter's face, and more time looking around the background), compared to typically-developing controls. Importantly, perspective modulated social attention in both groups; talking about an unfamiliar other reduced attention to potentially distracting or resource-demanding social information, and increased looks to non-social background. Social attention did not differ between self and familiar other contexts- reflecting greater shared knowledge for familiar/similar others. Autistic participants spent more time looking at the background when talking about an unfamiliar other vs. themselves. Future research should investigate the cognitive mechanisms underlying this effect.

Keywords: Perspective taking, Autism, Eye-Tracking, Real-Life Social Interactions, Topic of Conversation

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Lay Summary: Previous lab-based studies suggest that autistic individuals are less attentive to social aspects of their environment. In our study we recorded the eye movements of autistic and typically developing adults while they engaged in a real-life social interaction with a partner. Results showed that autistic adults were less likely than typically developing adults to look at the experimenter's face, and instead were more likely to look at the background. Moreover, the topic of conversation (talking about self vs. others) modulated the patterns of eye movements in autistic and non-autistic adults. Overall, people spent less time looking at their conversation partner's eyes and face, and more time looking at the background, when talking about an unfamiliar other compared to when talking about themselves. This pattern was magnified among autistic adults. We conclude that allocating attention to social information during conversation is cognitively effortful, but this can be mitigated when the topic of conversation is familiar.

Autism spectrum disorder (ASD) is a pervasive neurodevelopmental condition, diagnosed on the basis of impairments in social-communication and a restricted and repetitive pattern of behaviour and interests (American Psychiatric Association, 2013). Two key cognitive-level mechanisms that underpin social-communication ability are theory of mind (ToM) and social attention (Chevallier, Kohls, Troiani, Brodtkin, & Schultz, 2012; Kalandadze, Norbury, Nærland, & Næss, 2018). ToM is the ability to represent the mental states of the self and others in order to explain and predict behaviour (Premack & Woodruff, 1978). It is widely believed to be impaired/diminished among autistic people¹ (Baron-Cohen, Leslie, & Frith, 1985; Happé, 1994; Moran et al., 2011). Social attention refers to the ability and motivation to attend to, as well as coordinate attention with, a social partner during interaction (e.g., through joint attention, use of non-verbal gestures, including eye contact, and orientation and focusing of the visual system toward one's partner), and is also known to be atypical in autism (Chita-Tegmark, 2016). Social attention can be modulated through eye gaze, because we send and receive a great deal of social information through use and shifting of gaze (Cañigueral & Hamilton, 2019). It is particularly notable, therefore, that social-communication and ToM impairments in autism are associated with an atypical social attention distribution (Swettenham et al., 1998; Senju, 2013; von dem Hagen, Stoyanova, Rowe, Baron-Cohen, & Calder, 2013).

Reduced eye gaze to social stimuli during experimental tasks has been reported from early in development among autistic people (Bhat, Galloway, & Landa, 2010; Chawarska, Macari, & Shic, 2013; Dawson, 1991). In particular, several studies have indicated that autistic individuals are less attentive to social stimuli- and faces, in particular- than their typically developing (TD) counterparts (Bird, Press, & Richardson, 2011; Nakano et al., 2010; Riby & Hancock, 2009; von Hofsten, Uhlig, Adell, & Kochukhova, 2009). Furthermore, eye-tracking research shows that

¹ We acknowledge recent debates about the terminology used to describe autism, and in this paper adopt the identity-first language recommended by autistic adults and parents in Kenny, Hattersley, Molins, Buckley, Povey, and Pellicano (2016).

social attention in autism is associated with reduced gaze to the eyes and increased gaze to the mouth while scanning faces online, which is opposite to what tends to be observed in TD individuals (Chita-Tegmark, 2016; Corden, Chilvers, & Skuse, 2008; Guillon, Hadjikhani, Baduel, & Rogé, 2014). However, more recent literature has indicated comparable patterns of social attention towards the eyes and faces among TD and autistic individuals (Bar-Haim, Shulman, Lamy, & Reuveni, 2006; Fletcher-Watson, Findlay, Leekam, & Benson, 2008; Van Der Geest, Kemner, Verbaten, & Van Engeland, 2002). The mixed findings about this aspect of social attention in ASD may arise from the fact that different types of stimuli have been used across the studies (ranging from images of isolated faces, static cartoon/natural images, dynamic videos etc.). Plus, in almost all of these studies, the social partner/stimuli was not physically present, making it hard to generalise these results to everyday, real-world social interactions. It is, of course, essential to be able to generalise from experimental results to real-world behaviour, especially since the difficulties that autistic individuals experience with social interaction have been attributed to a specific difficulty *using* language appropriately in social contexts, rather more general cognitive impairments (Tager-Flusberg, 1999). Arguably, the paucity of research on how autistic individuals navigate face-to-face social interactions has hindered progress in the field.

The only study that we are aware of to employ eye-tracking methods to investigate real-world social interactions among autistic adults was conducted by Freeth and Bugembe (2019). They found that autistic adults were less likely to look at their social partner's face than were TD adults, especially when the partner's gaze was directed at them (Freeth, & Bugembe, 2019). In line with previous studies, Freeth and Bugembe also found that non-autistic individuals had increased fixations on the eyes of their social partner compared to their mouth, but this was not the case in autism (Chita-Tegmark, 2016). Yet, evidence from studies of individual differences in the general population is not entirely consistent with the evidence provided by Freeth and

Bugembe's case-control study. Neither, Vabalas and Freeth (2016), nor Freeth et al. (2013), found a significant correlation between the number of autistic traits self-reported by neurotypical adults and the number of looks to the experimenter during a live interaction with a social partner (Freeth, Foulsham, & Kingstone, 2013). On the other hand, Vabalas and Freeth (2016) did find that participants with higher numbers of autistic traits manifested in a reduced tendency to explore the scene visually. The authors concluded that this indicates a local visual processing bias in autistic individuals, as they pay more attention to the details of specific areas in the scene, and consequently visually explore the scenes less.

Recent evidence suggests that the pattern of eye movements during real-life interactions is further modulated by topic of conversation among autistic people. For example, Nadig et al. (2010) showed that autistic individuals were more likely to look at the face of their conversation partner when talking about a topic of circumscribed interest than when talking about a general topic that they were not especially interested in. Likewise, Hutchins and Brien (2016) observed that, during a Skype conversation, autistic children were less likely to look at the experimenter's eyes when talking about emotions than when they were discussing general topics concerning occupations and lifestyles. Perhaps discussing a familiar topic or a topic that does not involve emotion understanding (i.e., mentalising) with a social partner involves a lower processing cost than does discussion of an unfamiliar topic or a topic that requires emotion understanding. This is in line with numerous studies that have found higher levels of gaze aversion when autistic and TD individuals reply to questions that are difficult in nature (i.e. involve a high processing load; Doherty-Sneddon, Bruce, Bonner, Longbotham, & Doyle, 2002; Doherty-Sneddon, & Phelps, 2005; Glenberg, Schroeder, & Robertson, 1998). This is important because social-communication skills in autistic people may be scaffolded when discussing topics that are familiar to them, or generally easy to process.

In the current study, we explored this by comparing eye movements during a discussion between the participant and the experimenter about the participant themselves, a person well-known to the participant, and a person that was unfamiliar to the participant. Previous research suggests that friends may have a better understanding of each others' minds than strangers (e.g. Savitsky, Keysar, Epley, Carter, & Swanson, 2011), and that the quality of social interaction is enhanced between pairs of friends vs. strangers (Pollman & Krahmer, 2017). Thus, we reasoned that discussions about the self and a familiar other might yield more typical patterns of eye gaze among autistic participants than discussions about an unfamiliar other, because self-relevant information is easier to process and structures cognition better than information relevant to others (especially unfamiliar others), among both TD people (Kuiper, & Rogers, 1979; Sui, & Humphreys, 2015; Symons, & Johnson, 1997) and autistic people (e.g., Lind, Williams, Nicholson, Grainger, & Carruthers, 2019; Williams, Nicholson, & Grainger, 2018; Grainger, Williams, & Lind, 2014).

It is clear that there is a lack of research comparing how mentalising during real-life social interactions influences the eye gaze behaviour in autistic and TD individuals. Hence, this study was set to investigate two objectives. The first aim was to compare the patterns of eye movements between autistic and TD individuals during real-life social interactions, where the communication partner was physically present and language was unstructured. The second aim was to establish the extent to which gaze to social and non-social aspects of the environment differ when autistic and TD participants are prompted to think about themselves, a familiar other person, and an unfamiliar other person. We believe this would allow us to compare the processing costs of mentalising about the self and others in autism. The comparison between self, a familiar and an unfamiliar other would also help us to gain a better understanding of self-referential processing in autism.

In this study, participants first read a short scenario describing a male or a female ‘unfamiliar’ character. The scenarios were identical in terms of content (i.e. the characters’ hobbies, occupation etc.), differing only in the gender of the main character (selected to match each participants’ gender). Relevant cues were given in the scenarios so participants could answer questions about the unfamiliar other. Afterwards, participants engaged in a semi-structured conversation with the experimenter, answering questions about everyday life activities. These questions were either related to the participant themselves, or to someone the participant knew (e.g. one of their parents or a sibling), or to the character in the scenario the participant had just read (e.g. "Tell me somewhere you/your mother/Marina—the character in the scenario—would like to go over Christmas and why you think that?"). These questions were designed to elicit a short dialogue between participants and the experimenter also to encourage participants to mentalise about different people. Participants’ answers and eye movements were recorded using a mobile eye-tracker and a voice recorder.

Previous eye-tracking research into social attention in autism has revealed mixed findings, partly due to methodological differences (i.e., physical presence of social partner, diagnostic criteria for ASD). On one hand, lab-based experimental tasks suggest that autistic people attend significantly less to eyes/faces than TD people (Chita-tegmark, 2016), but during real-world face to face interactions Vabalas and Freeth (2016) showed that individuals who have stronger autistic traits are less likely than TD individuals to visually explore the environment (no difference in looks to people). Thus, in line with theories of atypical attention distribution in autism, we tested the prediction that autistic individuals would be less likely to look at their conversation partner’s eyes, compared to TD individuals. Also, previous literature has shown that people are more likely to look at their conversation partner’s face when talking about their own topic of interest or a topic that is easier for them to talk about (Nadig et al., 2010). Hence, we tested the prediction that participants would exhibit a higher likelihood of fixations on their

partner's face when talking about self and familiar others (easier topic to talk about, thus reduced mentalising costs) compared to an unfamiliar other. Further, this should be even more pronounced in autistic people, due to higher processing costs of mentalizing about unfamiliar topics/people.

Method

All methodological procedures were pre-registered on the Open Science Framework (OSF) website (see <https://osf.io/g485j/>).

Participants

Initially, a total of 53 participants were recruited using the Autism Research at Kent (ARK) database. Participants on the database were recruited from a community sample in the areas of Kent, Essex and London in the U.K., using a variety of recruitment strategies (e.g., newspaper adverts, contacting local groups, autism support groups and word-of-mouth). We deliberately avoided using university students to minimise differences in socioeconomic status between the groups. Three participants had to be excluded from the analysis due to technical problems (i.e. the experimenter could not obtain a successful calibration). Hence, the final sample consisted of 24 autistic and 26 TD participants, consistent with our pre-registered target sample size. These sample sizes were chosen a-priori to be comparable or even exceed the sample sizes used in previous research that has examined eye movements during real-world interactions among autistic and TD participants (e.g. Hutchins & Brien, 2016; Nadig et al., 2010; Vabalas & Freeth, 2016), and our own previous work on pragmatic language comprehension in autistic adults (e.g. Barzy, Black, Williams, & Ferguson, in press; Black, Barzy, Williams, & Ferguson, 2019; Black,

Williams, & Ferguson, 2018; Ferguson, Black, & Williams, 2019). Post-hoc calculations of power were conducted given the current sample size using the *simr* package in R (Green & MacLeod, 2016), and returned an estimated power of 87.9% with the significance level of $\alpha=.05$ on 80% of occasions (as suggested by Cohen, 1988).

Participants in the two groups were matched on age, gender and IQ (measured by the Wechsler Abbreviated Scale of Intelligence; WASI; Wechsler, 1999; see Table 1 for demographic information). None of our participants had a diagnosis of dyslexia or reading comprehension impairments, and all were native speakers of English. All autistic participants had a formal diagnosis of Autistic Disorder, Asperger's Syndrome or Pervasive Developmental Disorder Not-Otherwise Specified (DSM-IV or 5; American Psychiatric Association, 2013). Module 4 of the Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2000) assessed the current autistic characteristics of autistic participants. ADOS assessments were conducted by a trained, research reliable researcher (see Table 1), and videos were double-coded to ensure reliability of scoring (inter-rater reliability was found to be excellent with intraclass correlation of .89). All participants completed the Autism-spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) as a self-report measure of autistic traits.

Table 1. Demographic information (means and std. errors) of participants in each group, where
 *** $p < 0.001$.

	Autistic (N=24)	TD (N=26)	<i>F-value</i>	<i>p-value</i>	η^2
Sex (m:f)	17:7	18:8	-	-	-
Age (years)	33.79 (11.14)	34.77 (17.40)	0.23	.816	0.067
Verbal IQ	102.33 (11.23)	99.96 (9.31)	0.82	.419	0.229
Procedural IQ	106.75 (20.24)	103.35 (11.51)	0.74	.464	0.206
Overall IQ	104.71 (15.66)	102.00 (10.49)	0.72	.473	0.204
Total AQ	31.29 (9.02)	19.31 (8.28)	4.90	<.001 ***	1.383
ADOS2 Module4	8.00 (5.35)	-	-	-	-

Materials and design

In order to establish an unfamiliar other, a short scenario was written by the experimenters (in two versions, describing a male or female character, matched to the participant's gender). The scenario provided general information about the character (e.g. their occupation, where they are from, their hobbies; see Table 2 for the scenarios).

Nine questions, similar to those used in Vabalas and Freeth (2016), were designed to encourage conversation between the experimenter and the participant (see Appendix for the full set of questions). Participants were prompted to answer each question for themselves, for someone they know well (e.g. one of their parents or siblings), and for the unfamiliar character that was introduced in the scenario (e.g. "Tell me somewhere you/your mother/Marina would like to go over Christmas and why you think that?"). The questions were designed so that information in the scenario would provide some prompt to the unfamiliar other's perspective, but participants would need to make further independent inferences about the character to elaborate with additional information (i.e. scenarios and questions were designed to encourage

participants to mentalise about familiar and unfamiliar others). Questions were presented in the same order to all participants. Thus, the experiment employed a 3 x 2 mixed design, crossing the within-subjects variable Topic (Self/familiar other/unfamiliar other) with the between-subjects variable Group (ASD/TD).

Table 2. Scenarios describing a female/male ‘unfamiliar’ character.

Scenario describing a female character	Scenario describing a male character
<p>Marina is from Rome in Italy. She is a 32-year-old chef, who loves cooking Italian food and baking cakes. She owns an Italian restaurant in London. Marina loves her family and likes to visit them in Rome regularly, especially on public holidays. She enjoys fashion and going shopping with friends. She also loves traveling in summer. For example, she really likes going to pretty little coastal towns in England where she can relax in the sun and read cookery books. She doesn't like rain at all so when the weather is wet, she tries her best to stay indoors. Marina also enjoys watching tennis and listening to classical music. She goes to see tennis matches or classical concerts in her free time. She has many Italian friends in London with whom she meets for a drink.</p>	<p>Jack is from Rome in Italy. He is a 32-year-old chef, who loves cooking Italian food and baking cakes. He owns an Italian restaurant in London. Jack loves his family and likes to visit them in Rome regularly, especially on public holidays. He enjoys watching football on TV with friends. He also loves traveling in summer. For example, he really likes going to rustic little coastal towns in England where he can relax in the sun and read cookery books. He doesn't like rain at all so when the weather is wet, he tries his best to stay indoors. Jack also enjoys watching tennis and listening to classical music. He goes to see tennis matches or classical concerts in his free time. He has many Italian friends in London with whom he meets for a drink.</p>

To assess participants' Theory of Mind abilities we used the animations task (Abell, Happe, & Frith, 2000). In this task participants watched a series of four silent animation videos, in which two triangles interacted. Afterwards, participants were asked to describe the interactions between the triangles and say how they think the triangles felt at the end of each clip. To achieve the highest score, participants had to describe the triangles' behaviour in terms of epistemic mental states, such as beliefs, intentions, and deception. Participants' audio responses were recorded for later transcription.

Procedure

Ethical approval for conducting this experiment was granted by the School of Psychology Research Ethics Committee, at the University of Kent. SMI mobile eye-tracking glasses were used to record real-life eye movements. A front-facing camera on the glasses recorded a video of the scene (field of view: 60° horizontal, 46° vertical; resolution: 1280 x 960pixels), as seen by participants, and binocular eye movements around this scene were recorded at a sample rate of 60Hz (with 0.5° accuracy). Corrective lenses of the appropriate prescription could be attached to the eye-tracking glasses if necessary.

Participants were tested in a quiet laboratory at the School of Psychology, University of Kent. After giving consent to participate, participants were asked to read the unfamiliar other scenario, with the character matched to their gender. They were told that they would have a conversation with the experimenter about themselves, a familiar other (of their choosing, e.g. their mother), and an unfamiliar other (the character introduced in the scenario). Next, participants were fitted with the eye-tracking glasses, the experimenter ensured that they were comfortable, and participants completed a 3-point calibration and validation procedure. The experimenter sat in a chair opposite the participant, approximately one meter away.

Participants were asked to choose a family member/friend that they could answer familiar other questions for, and were reminded that they did not need to restrict their responses for unfamiliar other questions to the information provided in the scenario, but they should try to guess/expand their answers based on this information. The aim was to encourage participants to converse longer with the experimenter and to mentalise about the characters in the scenarios. Each participant responded to 27 questions in total (nine questions, in each of the three Topic conditions). Participants were encouraged to talk for approximately 30 seconds for each

question. The experimenter prompted for further information when necessary, and responded naturally to participants' responses to facilitate the flow of conversation. The entire conversation task took approximately 30 minutes to complete. Finally, participants removed the eye-tracking glasses, and completed the animations task on a computer. The whole experiment took approximately 40 minutes to complete.

Results

All analysis procedures were pre-registered, and the full datasets and analysis scripts are available on the Open Science Framework web pages (see <https://osf.io/g485j/>).

Animations Task

To verify that ToM was diminished in our autistic sample, each verbal transcription was scored on a scale of 0–2 for accuracy (including reference to specific mental states), based on the criteria outlined in Abell et al. (2000). This resulted in a total score for each participant between 0 and 8 (with a higher score indicating better mentalizing abilities). Twenty percent of transcripts were scored by two independent raters. Inter-rater reliability across all clips was excellent according to Cicchetti's (1994) criteria (intraclass correlation = .85). Results showed that autistic participants were significantly impaired at describing the animations in terms of their mental states compared to TD participants ($M_s = 4.17$ vs 5.38 , respectively; $t(48) = 2.04$, $p = 0.047$, $d = 0.57$).

Eye movement data processing

SMI BeGaze analysis software (3.7.59) was used to prepare fixation data for analysis. First, annotations were manually inserted into the timeline for each participant to indicate the onset and offset of each verbal response, and to code for conversation topic (self, familiar other, unfamiliar other). Next, fixations during the verbal responses were assigned to one of four areas of interest (AOIs): the experimenter's eyes, face, body, background (see Figure 1). The background AOI was defined as any area in the scene except for experimenter. Analyses were conducted on the proportion of time spent fixating each AOI per condition and group, which was calculated separately for each participant and question (item) as: summed duration of fixations on a specific AOI / sum of all fixation durations on all AOIs.

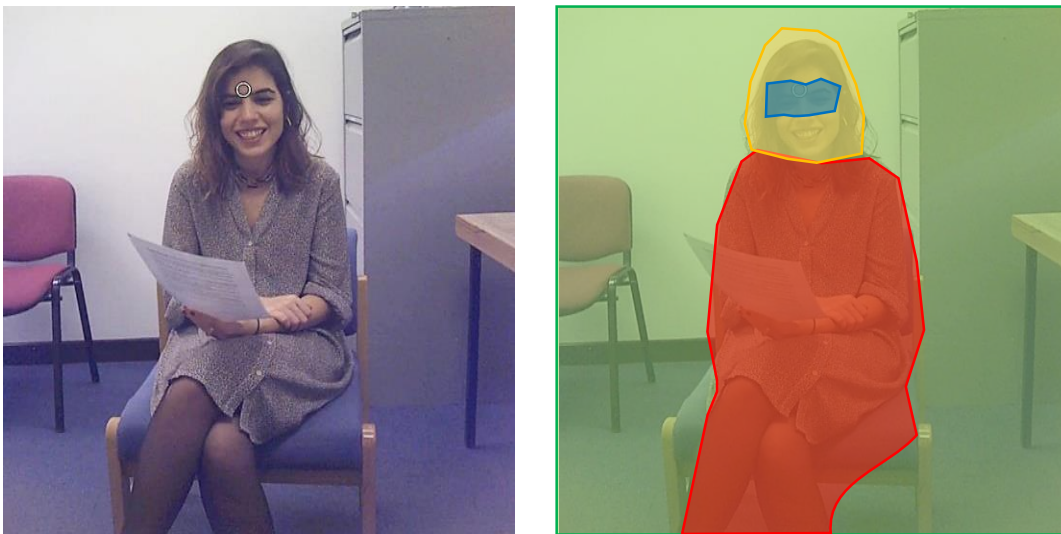


Figure 1. A screenshot of a typical view seen by participants during the experiment, and the corresponding AOIs for that view (eyes: blue, face: orange, body: red, background: green).

Linear mixed models and lmer in the lmer4 packages in Rstudio software were used to analyse the data (Bates, et al., 2014; Version 1.1.453, R Core Team, 2016). Four separate models were used to analyse data from each of the four AOIs (eyes, face, body and background). Each model included fixed effects of Topic and Group, and random effects of items and participants. Since the effect of Group had two levels, it was contrast coded (-.5 vs .5). To accommodate the three levels of Topic, deviation coded contrast schemes were used to compare each of the 'other' conditions to the baseline 'self' condition: Familiar other vs Self (Self (-.33), Familiar (.66), Unfamiliar (-.33)), and Unfamiliar other vs Self (Self (-.33), Familiar (-.33), Unfamiliar (.66)). Models also included the maximal random structure, including crossed random slopes for Group and Topic within items, and crossed random slopes for Topic within participants. When the model did not converge the random slopes that accounted for the least variance were removed (as suggested by Barr, Levy, Scheepers & Tily, 2013). Details of the final models used to analyse data for each AOI are presented in the supplementary materials. Note that due to space constraints, only significant effects are presented in the text. Full statistical effects are presented in Table 3.

Table 3. Model Estimate, Standard Error (SE) and t/z value for each measure in each region, where * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

	<i>Est.</i>	<i>SE</i>	<i>t-value</i>
Eyes			
Topic: Self vs. FamiliarOther	-0.006	0.009	-0.589
Topic: Self vs. UnfamiliarOther	-0.041	0.009	-4.269 ***
Group	0.072	0.054	1.32
Topic: Self vs. FamiliarOther * Group	-0.023	0.019	-1.223
Topic: Self vs. UnfamiliarOther * Group	0.006	0.019	0.331
Face			
Topic: Self vs. FamiliarOther	-0.016	0.009	-1.793
Topic: Self vs. UnfamiliarOther	-0.021	0.009	-2.428 *
Group	0.134	0.052	2.557 *
Topic: Self vs. FamiliarOther * Group	0.011	0.017	0.627
Topic: Self vs. UnfamiliarOther * Group	0.031	0.017	1.763
Body			
Topic: Self vs. FamiliarOther	0.004	0.008	0.472
Topic: Self vs. UnfamiliarOther	0.005	0.008	0.587
Group	-0.014	0.040	-0.349
Topic: Self vs. FamiliarOther * Group	0.016	0.017	0.928
Topic: Self vs. UnfamiliarOther * Group	0.027	0.017	1.621
Background			
Topic: Self vs. FamiliarOther	0.012	0.012	1.066
Topic: Self vs. UnfamiliarOther	0.045	0.012	3.849 ***
Group	-0.181	0.054	-3.354 **
Topic: Self vs. FamiliarOther * Group	0.006	0.023	0.263
Topic: Self vs. UnfamiliarOther * Group	-0.050	0.023	-2.121 *

Eye movement analyses

Eyes: Analysis revealed a significant effect of Topic, with a greater proportion of fixation time spent on the experimenter's eyes when participants were talking about the self than when they

were talking about an unfamiliar other ($M = 0.24$ vs. 0.20). Neither the effect of Group nor the self vs familiar other Topic contrast was significant, and Group did not interact with Topic. Figure 2 shows the proportion of time spent fixating the experimenter's eyes in each condition and group.

Face: Analysis revealed a significant effect of Group, reflecting the expected reduction in social attention among autistic participants; autistic adults in the current study spent significantly less time than TD comparison adults looking at the experimenter's face ($M = 0.13$ vs. 0.26). A significant effect of Topic showed that, overall, participants spent a greater proportion of time fixating on the experimenter's face when they were talking about the self than when they were talking about an unfamiliar other ($M = 0.21$ vs. 0.19). Fixation patterns on the experimenter's face did not differ between self and familiar other conversation topics, and Group did not interact with either Topic contrast. Figure 3 shows the proportion of time spent fixating the experimenter's face in each condition and group.

Body: None of the effects reached significance on this AOI.

Background: The effect of Group was significant, replicating previous research in showing that autistic adults spent a greater proportion of time fixating the background, than the TD participants ($M = 0.50$ vs. 0.33). The effect of Topic was also significant, reflecting a greater proportion of fixations on the background when participants were talking about an unfamiliar other compared to when they were talking about the self ($M = 0.43$ vs. 0.39). No difference in fixations to the background was found between self and familiar other conversation topics.

Moreover, Group significantly modulated the effect of self vs unfamiliar other Topic. To examine this effect further, post-hoc tests compared fixations on the background for self vs unfamiliar other Topics, separately for each Group. In the autistic group, the effect of Topic was significant ($Est. = 0.069$, $SE = 0.019$, $t = 3.598$, $p < 0.001$), showing a greater proportion of fixations on the

background when participants were talking about an unfamiliar other compared to when they were talking about the self ($M = 0.54$ vs. 0.47). In the TD group, the effect of Topic did not reach significance ($Est. = 0.020$, $SE = 0.013$, $t = 1.480$, $p = 0.139$), thus fixation patterns around the background did not differ between self and unfamiliar other conversation topics among TD adults.

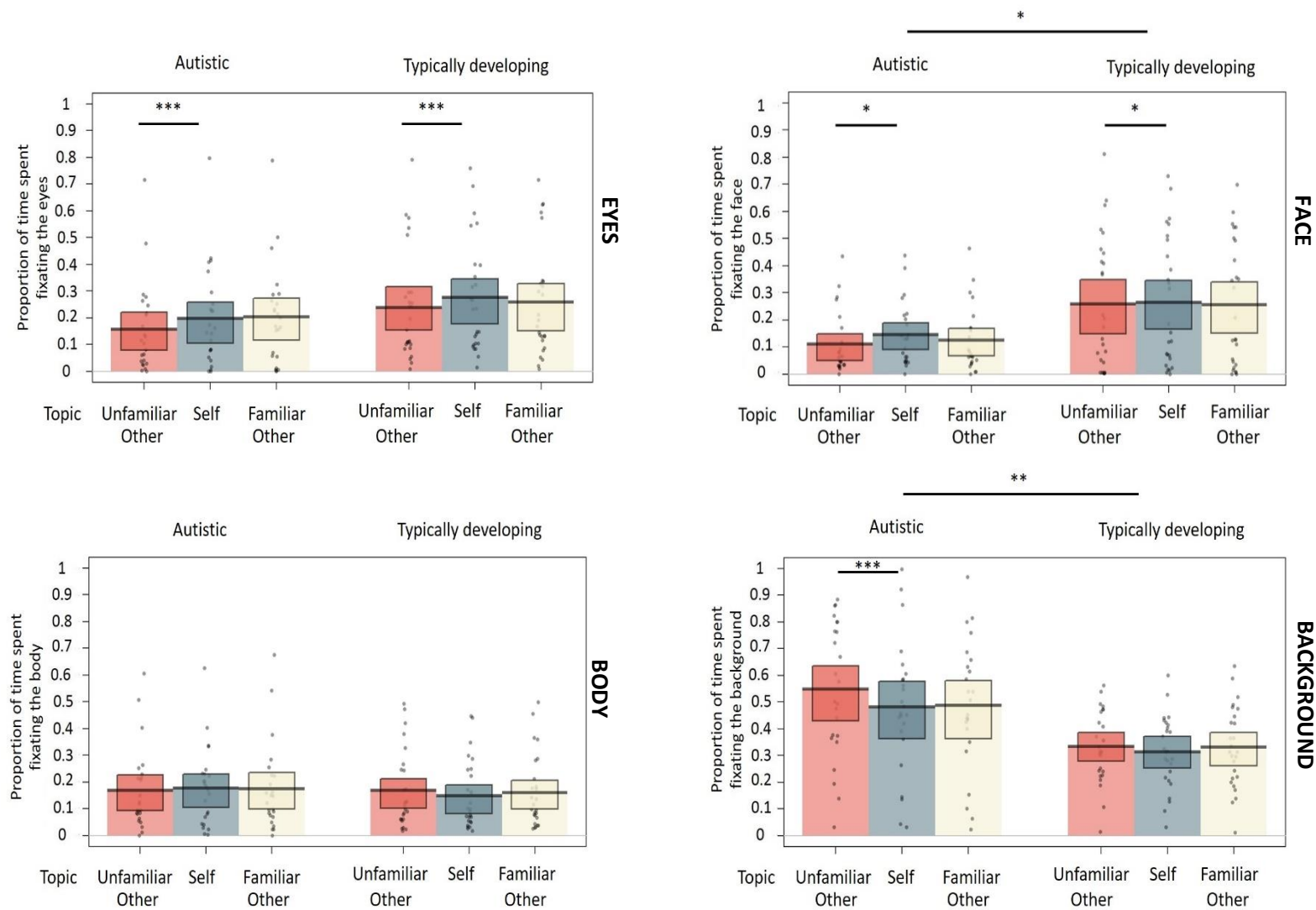


Figure 2. The proportion of time spent fixating each AOI in each condition and group (top left: eyes, top right: face, bottom left: body, bottom right: background). The plots show raw data points, a horizontal line reflecting the condition mean, and a rectangle representing the Bayesian highest density interval. Asterisks indicate significant differences between conditions (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Discussion

In a pre-registered experiment, we tested two novel objectives. First, we studied the pattern of eye movements during real-life social interactions in autistic and non-autistic individuals, a topic which has received little attention. Second, in the first study of its kind, we explored whether patterns of eye movements differ when individuals take the perspective of self vs. others. Specifically, we were interested to see whether the pattern of gaze to social aspects of environment (i.e. the experimenter here) differs when people (with and without ASD) mentalise about 'self' vs. 'someone they know' (a familiar other) vs. a 'stranger' (an unfamiliar other).

Regarding between-group differences in eye movements, we found that autistic participants spent significantly *less* time than TD participants looking at the face of the experimenter regardless of the topic being discussed. Conversely, autistic individuals spent significantly *more* time than TD participants looking at the background when talking with the experimenter (particularly when the conversation was about an unfamiliar other).

These findings are largely in line with findings from Freeth and Bugembe (2019), the only eye-tracking study other than ours to involve a physically-present social partner and autistic participants. Similar to the current findings, Freeth and Bugembe found that, overall, autistic individuals looked at the experimenter's face for a smaller proportion of time than did neurotypical comparison participants, at least in a condition in which the experimenter was directly looking at the participant (which is equivalent to our study, in which the experimenter always looked at the participant). However, our results contrast with those of Nadig et al. (2010), who did not observe any significant between-group differences in proportion of time spent looking at the social partner's face during online social interaction. There are several issues to consider when comparing Nadig et al.'s results to our own, however. The first is that the sample size in Nadig et al. was relatively small ($N = 12$ ASD and $N = 11$ TD participants in their study

compared to $N = 24$ and 26 respectively in our study). As such, Nadig et al.'s study had particularly low statistical power to detect between-group differences, which could, potentially, have led to a type II error. The second issue is that Nadig et al.'s study used children, rather than adults. One possibility is that social attention follows an atypical developmental trajectory in ASD. It is conceivable that autistic children show typical patterns of eye gaze to faces, and that atypicalities only emerge later in development, perhaps as a result of increasing aversion to direct eye contact, rather than because of a core representational difficulty. This latter possibility seems unlikely, given early-emerging difficulties with several aspects of social attention (including joint attention). However, given that very little is currently known about gaze to social stimuli in real-life social interactions among autistic people, it might be beneficial for future studies to explore this issue and attempt to replicate findings among both children and adults. One important finding in the current study was that significant between-group differences in the proportion of time spent looking at the eyes of the experimenter/social partner did not emerge. As noted in the Introduction, there is a question about the extent to which gaze to eyes is impaired/diminished in ASD. While several studies have reported reduced gaze to eyes among autistic people (Chita-Tegmark, 2016; Corden, Chilvers, & Skuse, 2008; Guillon, et al., 2014), other studies have failed to observe any such reduction (Bar-Haim, et al., 2006; Fletcher-Watson et al., 2008; Van Der Geest, Kemner, Verbaten, & Van Engeland, 2002). There is, arguably, a need for this issue to be addressed in further eye-tracking studies involving live, physically-present social partners. The presence of live social partners adds ecological validity in studies of social attention and, in this way, the current study adds weight to the notion that gaze to eyes is not diminished among autistic adults during real-world interactions.

Regarding within group patterns of performance across conditions, we found that individuals in both groups were more likely to look at the experimenter's eyes and face when talking about themselves compared to an unfamiliar other. This is line with our prediction and shows that topic

of conversation can modulate social attention in both autistic and neurotypical adults. Arguably, these patterns reflect the differential costs of processing information/mentalising about oneself vs. an unfamiliar other. Because self-relevant information is processed more easily and efficiently than information about others, especially unfamiliar others (see Lind et al., 2019), it may be that social attention is facilitated by the reduction in cognitive load associated with processing self-relevant vs. other-relevant information. This idea is in keeping with findings that there is an increased cognitive load associated with representing the mental states of others when those mental states differ from one's own compared to representing others mental states that are the same as one's own (Apperly, Back, Samson, & France, 2008; Schneider, Lam, Bayliss, & Dux, 2012). The fact, however, that attention to faces was reduced among participants with ASD even in the self- condition suggests that the advantage conferred by processing self-relevant over other-relevant information is not sufficient to overcome entirely the social attention difficulties observed in autistic people.

When it came to (non-social) eye gaze toward the background, we found a particularly important interaction between group and topic. Autistic participants showed significantly increased gaze toward the background compared to TD participants across all three topics of conversation, which likely reflects the social and cognitive load of managing the interaction (Doherty-Snedon, Whittle, & Riby, 2013). However, the between-group difference in gaze to the background was reduced in the self-condition relative to the unfamiliar-other condition. This suggests that social attention was facilitated by self-reference among autistic participants, which is an important and novel finding. However, an alternative explanation for this particular finding is that autistic participants simply found it more difficult to recall details of, or construct details about, the unfamiliar other than they did to generate self-relevant information. While it is well-established autistic adults have difficulties with this kind of recall or construction process (e.g., Lind et al., 2014), we think it is unlikely that these difficulties affected patterns of eye-tracking in the current

study. Notably, at the beginning of the experiment, the experimenter explicitly instructed the participant that the conversation task was not a memory test. Rather, the participant was encouraged to base his/her responses on what they think about the characters and not solely on what they read in the scenarios.

Several questions remain to be answered that are beyond the scope of this experiment. For example, it would be important to explore what the moderator cognitive mechanisms underlying this atypical visual attention are. Hutchins and Brien (2016) demonstrated that working memory abilities are correlated with number of fixations on the experimenter's eyes (higher working memory scores resulted in more looks at the experimenter's eyes). So, further work needs to be carried out to establish whether executive functions modulate visual attention during real-life social interactions. Plus, previous studies have established that there are differences when looks to the mouth and eyes are coded separately, with autistic participants being more likely to look at the mouth of the experiments compared to their eyes (Chita-Tegmark, 2016). In this study fixations on the mouth were aggregated with looks to other regions of the face, except for the eyes (as per our pre-registered analysis plan), so future research should separate these regions and explore this further.

In conclusion, this study explored the eye gaze behaviour during real-life social interactions, when autistic and non-autistic adults processed information about themselves, someone they know, or a stranger. Our results provide further evidence that social attention is atypical in ASD and that adults with this disorder show a pattern of eye gaze characterised by increased focus on non-social aspects of a scene at the expense of eye gaze toward (at least some) social aspects of the scene. Moreover, the current results add to evidence that the type of information being processed during conversation influences patterns of eye gaze/social attention. It is clear that social attention has a processing cost attached to it and this can be mitigated when the topic of conversation is relatively cognitively undemanding, i.e. relating to the self or a familiar

other. This mitigation might enhance social attention in autistic people particularly. Further research into this question could be beneficial not only for our understanding of ASD, but also for our understanding of the underlying basis of social attention more generally.

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Appendix

Full set of experimental questions in each condition. Note that for each of the items below, conditions are listed in the order: Self, Familiar Other, and Unfamiliar Other.

1a. Tell me somewhere you would like to go over Christmas and why you would like to go there?

1b. Tell me somewhere your mother/father would like to go over Christmas and why she/he would like to go there?

1c. where do you think Marina/Jack would like to go over Christmas and why you think Marina/John would like to go there?

2a. Tell me something you have to do during the week and something you like to do over the weekends?

2b. Tell me something your mother/father has to do during the week and something she/he likes to do over the weekends?

2c. what do you think Marina/Jack has to do during the week and what do you think she/he would like to do over the weekends?

3a. could you tell me about a dish that you like to eat and whether you can cook it?

3b. could you tell me about a dish your mother/father likes and whether she/he can cook it?

3c. could you tell me about a dish that you think Marina/Jack likes and whether you think she/he can cook it?

4a. Tell me what kind of programs you like to watch on TV and why do you like watching it?

4b. Tell me what kind of programs your mother/father likes to watch on TV and why she/he likes watching it?

4b. Tell me what kind of programs you think Maria/Jack would like to watch on TV and why you think she/he would like watching it.

5a. Tell me one thing you like about living in England and one thing you don't like about living in England?

5b. Tell me one thing your mother/father likes about living in England and one thing she/he doesn't like about living in England?

5c. tell me one thing you think Marina/Jack likes about living in England and one thing you think she/he doesn't like about living in England?

6a. Name a place you would like to visit in England and why would you like to visit there?

6b. Name a place your mother/father would like to visit in England and why she/he would like to visit there?

6c. Name a place you think Marina/Jack would like to visit in England and why you think they would like to visit there?

7a. Tell me what you like to buy when you go shopping and why you like to buy it?

7b. Tell me what your mother/father likes to buy when she/he goes shopping and why she/he likes to buy it?

7c. tell me what do you think Marina/Jack would like to buy when she/he goes shopping and why you think she/he would like to buy it?

8a. Tell me something you like to do in your spare time, like a sport or an activity, then describe some of the rules of this sport/activity?

8b. Tell me something your mother/father likes to do in her/his spare time, like a sport or an activity, then describe some of the rules of this sport/activity?

8c. tell me something you think Marina/Jack likes to do in her/his spare time, like a sport or an activity, then describe some of the rules of this sport/activity?

9a. Tell me who is your favourite celebrity and why you like him/her?

9b. Tell me who is your mother/father's favourite celebrity and why she/he likes him/her?

9c. Tell me who you think is Marina's/Jack's favourite celebrity and why you think Marina/Jack would like him/her?