Patterns of gaze behavior during live interactions in adults and adolescents with autism or high autistic traits : a systematic review

Lucile Bottein[1,2] & Antonia F de C Hamilton[1]

[1.] UCL Institute of Cognitive Neuroscience, 17-19 Queen Square, London WC1N 3AZ, UK;

[2.] Corresponding author phone number: 06 77 57 87 76, email: lucile.bottein.18@ucl.ac.uk

Abstract

Background: Differences in social gaze are part of the diagnostic criteria for autism spectrum condition (ASC) but most studies examining gaze in individuals with autism or high autistic traits use computerized methods that bear little resemblance to authentic conversations. Progress in eye-tracking now allows the use of live interaction paradigms. We report a systematic review of this emerging literature.

Methods: 14 studies were found that explored social gaze in adults and adolescents with autistic traits or an ASC diagnosis, using a live or believed-to-be-live interaction and modern eye-tracking technology.

Results: We find mixed results: when gaze is localized to broad regions (face, body, and background), patterns appear similar in all participants. However, when gaze is localized to precise regions (eyes, mouth, and nose) more group differences are found. Specifically, gaze to the eyes seems somewhat consistently reduced in individuals with autism or autistic traits. However, these participants appear to modulate their gaze according to contextual factors similarly to typically-developing individuals(*e.g.*, looking less towards the face when speaking than listening).

Conclusion: We discuss these results in relation to two dominant theories of autism: low social motivation and aversion-to-the-eyes. The finding that individuals with autism or autistic traits seem to specifically avoid the eyes but show facial orienting and gaze modulation similar to typically developing individuals lends supplemental support to aversive rather than motivational theories of ASC.

Gaze is a key tool for communication in social interactions and social gaze is often assumed to be impaired in individuals with autism spectrum condition (ASC) or high autistic traits[1]. Many scientific studies of gaze have used computerized stimuli in carefully controlled lab settings to explore differences in gaze to social images in autistic infants[1], children[2] and adults[3]. However, it is increasingly clear that gaze behavior in the lab does not necessarily match gaze in real-world situations[4–6]; much more complex and dynamic patterns of gaze can be found during real, face-to-face, social interactions. Few studies have tracked real-world social gaze in participants with high autistic traits, so it is not yet clear if gaze differences exist in this context or what this may mean for theories of autism and potential therapies. This paper aims to provide a systematic review of this emerging field and guide future research on individual differences in gaze behavior during real social interactions.

Why does real-world gaze matter?

Eye gaze is an unusual social behavior in that it allows us to simultaneously gather information about the social world (*perceive*) and communicate with others (*signal*)[6]. Before discussing autistic gaze, it is important to clarify what gaze in typically-developing behavior looks like and what theories can account for this. When typically-developing participants view humans in photographs and videos, they show preferential attention to faces and eyes over objects, regardless of saliency[7], suggesting that these features are processed as important social stimuli. This prioritization probably arises because faces provide useful social information about a person's identity, emotional state, attention, and even social status [8,9]. In other words, preferential attending to the eyes and face serves a crucial *perceptual* role, allowing a person to

[1] NB: To facilitate the readability of this paper, we will henceforth refer to "individuals with an ASC diagnosis or high autistic traits" as "individuals with high autistic traits", because both groups score highly on autistic trait questionnaires. This is in line with the methodological choice to include both clinical and non-clinical studies in the present review (see methods section for justification).

gain social information about others.

Recently, the development of robust wearable eye trackers has made it possible to track gaze patterns during real, *interactive* conversations. During a live interaction, gaze is used for more than perception; it is also deployed as a communicative tool *(e.g.,* looking intently at someone's eyes to signal interest in initiating a conversation[10]). Together, these perceptual and communicative roles are known as the dual function of gaze[11]. Classic studies on gaze to photos or videos fail to elicit the signaling role of gaze, and therefore neglect a large portion of social gaze behavior[6]. Studies which directly compare live interactions to viewing videos show that people look more to video faces than to live faces [4,5]. While lab studies might suggest a simple rule that more gaze-to-face relates to better social skills, the finding of lower gaze-to-face in live interaction implies that this rule does not directly translate to real world contexts. Similarly, findings from studies of passive face-viewing in autistic participants may also fail to apply in the context of a dynamic face-to-face interaction.

In typically-developing individuals, conversational gaze appears to, among other things, regulate conversational turn-taking: people tending to to avert their gaze when speaking and gaze more towards the eyes and face when listening [10,12–15], . Gaze can also be deployed to signal internal states such as attraction[16], embarassment[10], or dominance[11]. However, it remains unclear which of and how these communicative functions may differ in individuals with high autistic traits.

Social Gaze in Autism Spectrum Condition

ASC is a neurodevelopmental disorder primarily characterized by issues in social communication and interaction, accompanied by restricted and repetitive behaviors and

interests[17]. It is a particularly heterogeneous disorder with a range of clinical presentations and secondary conditions, making research on ASC particularly challenging. Unusual gaze is part of the diagnostic criteria in the ADOS-2 and DSM-5[17,18], but it is not specified in what manner this gaze is 'unusual' nor is it clear how this behavior -based on clinical observations- can be captured in the lab. The majority of research on social gaze in ASC has used computer-based eyetracking methods where participants view static images or videos of faces on a screen. Formal meta-analyses on such studies suggest that autistic children[2] and adults[19] show reduced gaze towards the eyes when compared with typically-developing peers. However, it should be noted that these results are in no way systematic. Furthermore, these studies –by using non-interactive stimuli- suppress the signalling function of gaze, which is a communicative behaviour of particular interest in autism. Additionally, live interactions may engage the senses in a heightened manner relative to pre-recorded videos. Sensory differences in ASC -which can manifest as both hypo and hyper-stimulation[20]- may cause autistic individuals to show considerably different gaze behaviors under the increased sensory load of live interactions. Using new wearable eyetrackers, it is possible to track real-world gaze behaviour and link clinical observation to lab studies. Thus, a new body of research on real-world social gaze in ASC is developing, which the present paper aims to critically review.

This review will be focusing on adults and adolescents with high autistic traits (both with and without diagnoses) rather than young children for two main reasons. Firstly, there is reason to suspect that at least some clinically relevant behaviors in ASC may present differently across the lifespan[21–23]. Notably, eye-gaze may be one of these evolving behaviors[24]. Second, there exist very little data on autistic children's gaze during *live* conversation collected via *eye-trackers,* so a review with our eligibility criteria cannot yet be conducted.

Despite inconsistent evidence concerning whether and how autistic individuals show different social gaze patterns, three major theories exist to make light of this. The first is the social motivation theory[25] which posits that individuals with ASC show reduced social orientation in their gaze due to diminished motivation to attend to socially relevant areas (people, faces, eyes). Thus, they are simply indifferent to social stimuli and are roughly as likely to look at or engage with objects. A second contrasting theory suggests that autistic individuals are not insensitive to all social stimuli, but rather find the eyes in particular to be aversive[26]. These two theories oppose each other as the latter supposes that autistic individuals actively avoid the eyes while the former states that they are indifferent to all social stimuli including both faces and eyes. Studies using fine-grained gaze-tracking to the eye region may be particularly useful to experimentally confront these theories. A third, more recent theory known as the dialectical misattunement hypothesis[27], states that differences in autistic gaze may arise from interactive and dynamic mismatches *between* individuals. Testing this requires tracking *both* conversation partners' gaze. We identified only one paper which reports data to this effect[28]. Thus, the studies reviewed in the present paper will be discussed only in relation to aversion versus social motivation theories.

Why Study Social Gaze in ASC?

The relevance of studying social gaze in autism is two-fold. Firstly, this research domain can help explain some of the social difficulties encountered by autistic individuals in live social interactions. Two alternatives exist: either individuals with high autistic traits are shown to have different patterns of social gaze relative to allistic individuals, or, no differences are found. As stated above, gaze serves a *perceptual* and *communicative* role during a live interaction. Thus, if social gaze behavior is different in autistic relative to allistic individuals, it can be inferred that

some social challenges experienced by autistic individuals may be due to e mutual misunderstandings in non-verbal communication If, instead, no differences in social gaze are found, then alternative explanations for communication difficulties should be considered. Secondly, and at a more general level, gaze research can serve to support or challenge contrasting theories of ASC, specifically the aforementioned aversion and social motivation theories. Both theories would be challenged if autistic individuals' social gaze is found to be indistinguishable from allistic individuals. If differences are found, the manner in which they arise can help distinguish between either theory. . Crucially, though, if differences are found, this research must not serve to catalog autistic 'deficits'. For example, it must not be immediately assumed that interventions must target this. Beforehand, research should clarify whether this reduced gaze is indeed related to missed non-verbal cues and to what extent misunderstandings occur reciprocally (i.e., allistic individuals mis-interpreting the non-verbal communication of their autistic interlocutors rather than or additionally to the opposite).

Methods for Tracking Social Gaze

Before reviewing results from studies on social gaze in individuals with high autistic traits, it is important to understand the methods used to track gaze in more detail. In recent decades, eye-tracking technology has developed substantially, from invasive methods[29] to desktop eye-trackers that require participants to keep their head steady in a frame, to new wearable eye-trackers embedded in a pair of glasses[30,31]. While wearable eye-trackers typically have lower temporal and spatial resolution compared to head-fixed eye-trackers, they allow participants to engage in natural conversation and other social behaviours which is critical if we wish to understand real-world gaze patterns. With the introduction of more affordable and accurate systems, there is now a clear increase in studies using eye-tracking in live social

interactions[32,33]. Eye-tracking is particularly suitable for autism research as it can measure subtle spontaneous social behaviours and is not reliant on language skills.

Analyses are usually based on Areas of Interest (AOIs) which are zones in the participant's visual field that have been selected as relevant. They can range in size from small (e.g., the nose) to large (e.g., the background or whole screen) according to research interests and available technology. A simple -and common- variable extracted from eyetracking data is the proportion of time a person spends gazing at a particular AOI within a trial. We summarize common methodological variations in Figure 1 and describe them in more detail below.

[INSERT FIGURE 1]

First, the AOIs which are selected in a research study are an important factor. Some studies may use large coarse-grained AOIs, for example distinguishing only face, body, and background. Others might use fine-grained AOIs that distinguish eyes from mouth. There are no standards for defining AOIs in social interaction research, and the possibilities will depend on both the research question to be answered and technology available. Furthermore, AOIs can be defined in different manners. Studies might use a large rectangular area over both eyes including the bridge of the nose, or smaller ovals that cover only the eyes themselves. Some studies include a 'nose' AOI and others leave it out. Some use automated face-detection tools such as OpenFace[34] to define AOIs and others use manual labelling. All these factors may impact the research results.

Second, studies using different conversation paradigms may have unique behavioral results related to this. It is possible that highly structured conversations in which one person always asks questions and the other gives short answers may produce different gaze patterns than more free-flowing conversations characterized by speech overlaps. Also, the conversation

partner's perceived gaze is a manipulable variable which is likely to impact participants' behavior. Indeed, sustained direct gaze is known to be much more arousing than averted gaze[35]. Finally, some studies measure gaze in live face-to-face interactions while others use interactions mediated by a video call system. In the latter, true eye contact is not possible because the webcam location does not match the eyes on the screen. Other studies implement a 'fake' conversation between a participant and a video clip where the participant believes they are speaking to a live human. Each of these paradigms provide a different balance between ecological validity and experimental control, thus potentially leading to different patterns of gaze behavior.

The Present Review

The brief outline above shows that gaze patterns in live social interactions are important in autism and recent technological advancements allow us to study this. The present paper therefore aims to provide a systematic review of current studies on social gaze in adults and adolescents with high autistic traits. We aim to understand (1) do gaze patterns differ between these individuals and their typically-developing peers ? (2) how do they differ? and (3) can this give us insight into the gaze indifference / gaze aversion theories about autism? To our knowledge, most existing reviews of gaze in adults and adolescents with high autistic traits using eye-tracking technology predominantly focus on gaze to passive stimuli and/or during non-conversational tasks [19,36–38]. One review[39] focuses on live interactions, but this paper includes studies with children and excludes non-clinical studies resulting in an overlap of only 4 studies between the present review and their's. Our choice to include non-clinical studies was made in line with the modern conceptualisation of autism as a continuum, where sub-clinical autistic

traits are thought to be continuously distributed amongst the general population[40], rendering the general population a relevant sample in the research on social gaze in ASC.

Methods

A general search on Google Scholar, an advanced search on the APA PsycInfo database using OVID (with key search terms related to ASC, communication and gaze (see Table A in the supplementary materials)), backwards citation searches, and ConnectedPapers were used independently by both authors to identify relevant studies. Each study was then jointly discussed to ensure compliance with eligibility criteria. We did not encounter any uncertain cases.

Both clinical (participants with an ASD diagnosis) and non-clinical studies (participants from the general population with autistic traits) exploring social gaze behavior in relation to autism or autistic traits were included. Studies were excluded if they a) recruited young children, b) measured gaze without eye-tracking technology, or c) did not include an interaction with a person at least *believed* to be live. Because of methodological heterogeneity, results were categorized by AOI (body, background, whole face, eyes, mouth, and nose) and modulatory patterns (gaze modulation according to conversational phase, conversant gaze, and belief in social presence). As methods and data were not consistent enough for a formal meta-analysis, we provide a narrative review of our findings.

Results and Review

Results

Figure 2 shows the selection process for articles included in this review. The advanced search on OVID resulted in an output of 193 papers. By checking titles and abstracts, 9 studies

were selected. A more detailed reading of these led to the exclusion of 3 papers (for lack of eye-tracking technology). In addition to the remaining 6 studies, 5 papers were found through ConnectedPapers, and 3 were found by examining reference lists. This resulted in a total of 14 papers tracking gaze in adults and adolescents with high autistic traits during a live (or believed to be live) interaction, of which 5 were non-clinical studies, and 9 were clinical. Summaries of these studies are available in Table B of the supplementary materials.

[INSERT FIGURE 2]

Review

Findings from Studies Involving a Non-clinical Sample

Firstly, studies using a non-clinical sample (members of the general public) will be reviewed. These studies measure autistic *traits* using validated scales (most often the Autism-Spectrum Quotient, or, AQ[41]). They permit larger sample sizes, but are limited in that findings cannot be directly applied to the clinical population in question. For demographic information about the participants in these studies, please see Table C in the supplementary materials.

In a seminal study, Freeth, Foulsham, and Kingstone[42] conducted an experiment in which 30 participants took part in a face-to-face structured interview with a confederate whose gaze was manipulated to alternate between direct and averted. Gaze was tracked to three broad AOIs (face, body, and background.) Results showed gaze-to-face was stronger during the question phase, in line with older findings[10]. However, AQ showed no relationship with viewing patterns.

In a video-mediated interaction, Von dem Hagen and Bright[43] found contrasting results. In experiment 2 of this study (experiment 1 did not meet eligibility criteria), 45 participants took

part in a live conversation with an experimenter over a video connection. The high-AQ group was found to look less towards the eyes and mouth of the confederate than the low-AQ group.

Mansour and Kuhn[44] found a more ambiguous relationship between AQ and social gaze. Their study exposed 68 university students to a pre-recorded interactive video which participants were either deceived into believing was live or knew was pre-recorded. They found no relationship between overall AQ score and dwell time to the face and eyes of the confederate in either condition. They did, however, find that scores on a *subset* of the AQ were positively related to reduced gaze-to-eyes regardless of condition and conversational phase. These findings point to the possibility that only certain autistic traits may be related to gaze differences.

So far, all of the studies reviewed used a one-sided interactive task in which the confederate led the conversation by telling a story or asking questions. Vabalas and Freeth[45] designed a study which included a role switch where the participant could ask questions and take on a different conversational role. For this study, 36 student volunteers underwent a live, face-to-face structured conversation with an experimenter who held a direct gaze throughout the interaction. In line with Freeth and colleagues[42], scores on the Broad Autism Phenotype Questionnaire (BAPQ) showed no effect on proportions of fixations to the face AOIs. However, BAPQ scores (especially the rigid subscale) were related to reduced visual exploration.

Hessels and colleagues[28] conducted the only study included here that examines gaze *between* two participants (rather than participant and confederate). This added complexity reflects the interpersonal approach outlined in the dialectical misattunement hypothesis. 96 participants were put into pairs and instructed to look at their partner for 5 minutes (with no speaking) through a skype-like 2-way-mirror setup which simulated eye-contact. On an

individual level, AQ (specifically the social skills and communication subscales) was negatively correlated with dwell time to the eyes (specifically the right eye), and positively correlated with dwell time to the nose. On an interpersonal level, pairs with relatively high AQ scores were engaged in 2-way gaze for less time, yet engaged in 1-way gaze for more time than pairs with low AQ scores. This study stands out due to its novel and creative approach, which may better represent some of the awkwardness of real encounters. However, with two participants in every interaction it may be hard to disentangle which behaviours are intrinsic to each individual person and which are specific to each pair in the study.

In addition to the variation in methods across these 5 non-clinical studies, there is little consistency in AOIs selected. To help make sense of the heterogeneity, we organized results by AOI (see Table 1 below). We also organized the results by contextual manipulation to establish whether participants high in autistic traits show the same *patterns* of adjustment according to context as individuals low in autistic traits.

[INSERT TABLE1]

Findings from Studies Involving a Clinical Sample

Studies which directly compare diagnosed autistic adults and adolescents with typically-developing individuals provide a stronger way to examine social gaze behavior in autism. We identified 9 eligible studies of this type for which we will provide a narrative review. For demographic information about their participants, please see Table D in the supplementary maetrials. Firstly, Wilkinson[46] recruited 19 males with ASC and 19 male controls to take part in a video-mediated interaction which participants were deceived into believing was live. Results showed an overall slight reduction in gaze to AOIs in the ASC group. The most robust differences were concentrated in listening portions and on the nose AOI (with a reduced dwell time to the nose in the ASC group). Wilkinson also found that these differences may have been triggered or exacerbated by contextual factors such as expression of negative affect and disfluent or densely informative speech.

Auyeung and colleagues[47] designed their study around a live, video-mediated interview with a confederate who maintained direct gaze. 32 males with ASC and 34 male controls took part in this study which aimed to evaluate the effect of oxytocin on gaze behavior in ASC. Results from the placebo group showed that the ASC group looked less at the eye region than controls. No group differences were found for the other AOIs. It is important to note that the medical context of the study may have impacted gaze behavior.

A study by Yoshikawa and colleagues[48] was able to manipulate the variable of social presence without resorting to a screen-based pre-recording. This is of interest because screen based interactions typically have an offset between webcam placement (above the screen) and

the face of the conversation partner (in the center of the screen) which could disrupt natural gaze behavior patterns. In this pilot study, 4 male adolescents with ASC and 6 male controls undertook 5 structured interviews alternating between a human conversant and a humanistic android. Results showed the ASC group spent less time gazing at the eye AOI of the human compared to the android and compared to the control group. No group differences were found in gaze to the whole face, although this remains only a pilot study.

More recently, Cañigueral and colleagues[49] studied 26 autistic and 26 typically-developing adults performing a question-answer task either face-to-face, over a live video call, or with a pre-recorded video. They found no overall differences in gaze to the eyes or to the mouth, and both groups looked more to the face when listening than when speaking. Surprisingly, the allistic participants were less likely than the autistic participants to look to the eyes at the start of the question phase. This study has the advantage of using a well-controlled design and a professional actor who was able to maintain very consistent behavior as the conversation partner. However, the conversation was highly structured with no opportunity for the participants to ask questions.

Freeth and Bugembe[50] examined gaze patterns in typically-developing and autistic participants in a conversation task which included a role switch in asking questions to further resemble real conversations. 12 autistic adults and 13 typically-developing controls participated in a live, face-to-face structured conversation with an experimenter whose gaze alternated between averted and direct. Autistic participants were found to spend less time gazing to the face, specifically during direct-gaze conditions (but not during averted conditions). In direct-gaze conditions, ASC data was significantly more variable than controls, suggesting the possibility of

underlying sub-groups. Furthermore, controls showed a preference for the eye region but the ASC group did not.

Despite a very similar design, Grossman and colleagues'[51] study from the same year had contrasting results. Like Freeth and Bugembe, they included a structured interaction with a role switch in question-asking, but this came after the passive viewing of a pre-recorded video. They found, in 12 adolescents with ASC and 19 controls, no significant differences in dwell time to the face or background in the live interaction. Perhaps the inconsistencies between this study and the previous one arise from the difference in sample age (adolescents versus adults).

In contrast, Barzy and colleagues[52] did find similar results to Freeth and Bugembe, that is, reduced gaze to the face in autistic participants. In their study, 24 autistic adults were compared with 26 controls in their gaze behavior during a semi-structured face-to-face conversation with a confederate. Results suggested that autistic participants gazed less to the face and more to the background, especially when the topic of conversation involved heightened mentalizing (talking about the preferences of an unfamiliar other as opposed to the self or a familiar other). Interestingly, this reduced gaze-to-face was not explained by a reduction in gaze-to-eyes; there were no group differences for this variable.

However, in a highly powered study, Clin and Kissine[53] failed to find this effect of reduced gaze to the face in autistic participants. They explored the gaze behavior of 40 autistic individuals (versus 40 controls) in a face-to-face paradigm requiring participants explain the meaning of various words to a confederate whose gaze was either direct or averted. Between-groups analyses revealed no significant differences between autistics and their typically

developing peers in the proportion of fixations to the eyes, mouth, face, or whole body of the experimenter.

All the studies mentioned up to this point (including the non-clinical papers) used conversation paradigms that were highly structured, which reduces their ecological validity but allows for strong experimental control. Hanley and colleagues[54] cleverly elicited a more natural conversation. Through a complex deceptive procedure, 11 individuals with ASC and 11 controls believed they were undertaking a color perception task (hence the head mounted eye-trackers). An issue with the tech was staged and participants were instructed to speak to an experimenter while it was being 'resolved'. No group differences were found in gaze to the whole face. The ASC group spent significantly less time looking at the eye AOI, and significantly more time looking at the mouth AOI than controls. Unfortunately, there was also a non-negligible confound of belief in the deception was introduced, with 7/11 controls not believing the deception against 1/11 autistic participants.

Identically to the non-clinical studies, we organized all of these results by AOI and contextual manipulation (see Table 2 below).

[INSERT TABLE 2]

Discussion

Here we provided a systematic review of 14 studies of real-world social gaze behavior in adults and adolescents with ASC or high autistic traits. In this small but growing research domain, we find that results are mixed but we can draw conclusions about differences between groups in terms of coarse-grained social orientation, fine-grained social orientation, and gaze modulation. We consider the limitations of these findings and wider implications for future research.

Do individuals with high autistic traits gaze less to faces and bodies?

Several studies of gaze behavior used coarse-grained AOIs, dividing the visual scene into face, body, and background. These analyses overwhelmingly showed no relationship between autism and gaze towards the body or background. 6 out of 9 studies which included a 'whole face' AOI found no group differences in gaze onto this region. In the three studies that did find effects, one found that differences were only marginal[46], another found that they related only to a *subset* of autistic traits [50], while the third found a straight-forward reduction in gaze to face in the ASC group[52]. Overall, these results suggest that there is little relationship between autism and gaze to face and body, implying that coarse-grained social orienting is similar between autistic and allistic individuals. This is surprising as both aversion and indifference theories for gaze in ASC posit that autistic individuals should show more gaze to the background and body as a result of omitting or avoiding the face. However, it is still possible that differences in gaze behavior arise at a more subtle level which is lost when considering only large AOIs.

A more precise analysis of facial AOIs reveals stronger evidence for differences in gaze behavior between individuals low and high in autistic traits. The most consistent result was

differences in gaze to the eye region. Some form of difference- even if only slight or restricted to a specific timeframe - was related to autistic traits in all except three[45,52,53] of 12 studies which included this AOI. Furthermore, out of the 9 studies which found differences, 7 showed *reduced* gaze towards the eyes by individuals with ASC/high autistic traits. These results suggest that high-resolution eyetracking data in live interaction contexts aligns with the common clinical observation that reduced gaze-to-eyes is associated with autism. However, this finding is not clear-cut; a similar review (albeit focusing on clinical studies) by Laskowitz and colleagues found that 5 out of 9 included studies measuring gaze-to-eyes found comparable patterns between autistic and allistic groups.. Differences in results may be partially related to our choice of including non-clinical studies, one possible explanation being that individuals with high autistic traits but no diagnosis may have never received explicit instruction or therapies to increase eye contact. More work is needed to strengthen the evidence base and allow for robust meta-analyses. .

If some people gaze less to the eyes, we might expect them to gaze more to other facial AOIs, notably the mouth. However, only 2 out of 10 studies including the mouth AOI found a positive relationship between autistic diagnosis/traits and gaze to the mouth. This may be because gaze away from the eyes is evenly distributed onto other AOIs, so any group differences become too small to detect with the sample sizes currently used. More research is needed to verify such an interpretation. The nose AOI may be a key region of interest. Only 2 studies have included this area, but both have found gaze differences associated with autistic diagnosis/traits, although in opposite directions. It is possible that gaze onto the nose has been included in the eye or mouth AOIs of past studies[46]. More work using high spatial resolution would be required to disentangle gaze data in these areas.

Modulation of Gaze

Beyond the analysis of AOI fixation times, it is of interest to investigate whether individuals with high autistic traits *modulate* their gaze differently according to conversational roles and other contextual factors. This could give insight into how autistic people use gaze in real conversations and which theories best explain the reduced gaze-to-eyes found in autistic individuals. Firstly, all 6 studies which examined the effect of conversational phase found that all participants modulated their gaze according to whether they were speaking or listening in a similar manner, with more gaze-to-face when listening than speaking. This implies that the conversational conventions of gaze and the use of gaze to gather additional information when listening, as widely reported for allistic participants[10,12,55], are present in people with high autistic traits.

For conversations implemented over a computer interface, it is possible to manipulate participants' belief in whether they are seeing a video recording or a live person, that is, their belief in social presence. 4 out of the 5 studies which included the effect of belief in social presence in their analysis found main effects of this variable on gaze data, regardless of group attribution. Indeed, both experimental groups were found to gaze less towards the eyes and/or face of their conversant when they believed the conversant to be live (i.e. able to see them). This is in line with the dual function of gaze theory[11]; participants show more gaze aversion in the live condition to avoid signaling too much interest or staring during a neutral conversation with a stranger. Participants with high autistic traits appear sensitive to these belief manipulations similarly to allistic participants.

Three studies explored the effect of confederate gaze as part of their experimental design. They found contrasting results; von dem Hagen and Bright[43] and Clin and Kissine[53] found no effect of conversant gaze in either group while Freeth and Bugembe[50] found that only the ASC group reduced their gaze-to-face in response to the experimenter making direct eye contact. Overall, studies which manipulate confederate gaze seem to yield ambiguous results, possibly because this factor is very hard to experimentally control in a realistic fashion.

Theories of gaze in autism

We can consider these results in relation to two major theories of social gaze in autism. The social motivation theory[25] suggests that autistic individuals are not motivated to attend or orient towards other people, whether eyes or face or body, but are just as likely to look at non-social points of interest. Thus, autistic participants might be predicted to show reduced gaze across all social AOIs. The gaze aversion theory[26], on the other hand, posits that autistic individuals find direct eye-contact to be too arousing -thus aversive-, and will show less gaze-to-eyes in order to avoid the induced arousal. Our review suggests that coarse-grained social orienting appears to be present in autistic participants, and this is not compatible with the social motivation theory. Furthermore, participants with autistic traits modulated their gaze according to conversational phase and belief in social presence in a similar manner to typically-developing participants, which suggests that they are sensitive to the signaling function of gaze. Again, this is suggestive of social motivation. In contrast, the specific differences found in the analysis of fine-grained AOIs centered on the eyes match the predictions of the gaze-aversion hypothesis. If individuals with autistic traits find the eyes to be particularly aversive but still want to gain social information during an interaction, it would make sense for them to gaze towards the face and modulate their overall gaze patterns similarly to their allistic

peers, all while avoiding the eyes. However, avoidance of eyes was not found to be universal in all studies, so more work is needed to understand when and how it occurs. In addition, other explanations of the data could still be possible. For example, it may be that unique gaze behavior in ASC is a result of decreased social awareness, increased cognitive demands for social interactions, or interpersonal mismatches[27,52–54]. Finally, it is also crucial to consider that the equivocal results found in these studies suggest that there simply aren't significant and reliable differences in gaze behavior between people high and low in autistic traits, at least in the specific samples included here (which were matched in IQ and verbal skills). In the same vein, it is possible that behavioral differences are masked by compensatory strategies such as looking *near* the eyes. This would explain the mixed results, given that each study delineated the eye-region differently, some including more space around the eyes than others.

Limitations & future directions

There are still some important limitations in our understanding of real-world social gaze in autism which are reflected in this review. Only a small number of published studies examine this topic, and the clinical samples were primarily composed of, male individuals without intellectual or verbal disabilities (see Tables C and D in the supplementary materials). It is possible that gaze behavior varies across the spectrum as well as according to gender and secondary conditions. Secondly it is possible that some form of stereotype threat relative to autistic individuals' presumed social incompetence may have been activated[56] causing biased results In the future, experimental designs could attempt to control for this. Additionally, new interaction paradigms offering different degrees of experimental control and ecological validity should be considered in the aim of minimizing the gap between lab interactions and authentic conversations. Virtual reality may be an avenue of progress in this aim[57]. On a more technical

level, future research should strive to use high spatial resolution to precisely track gaze to eyes and nose. Obtaining robust measures of an individual's propensity for gaze-to-eyes with quantification of test-retest reliability would also be a valuable step towards understanding how differences in real-world gaze behavior relate to other clinical symptoms and personality traits.

Finally, there is a dearth of ecologically valid research examining the *impact* of reduced gaze to the eyes on conversation quality in autistic adults. It may be that gaze-to-eyes is reduced in ASC but that this has no ramifications on communicative competence or information exchange due to compensatory strategies[58]. Indeed, mutual gaze to the face is often perceived as mutual eye-contact[59], meaning that interlocutors may not be able to subjectively distinguish gaze *near* the eyes from gaze *to* the eyes. It is also possible that conversations between two autistic individuals, presumably with less gaze-to-eyes overall, are as communicatively effective as allistic conversations[60]. As the specific impact of autistic gaze behavior on conversation quality is currently undefined, critical caution should be taken before designing interventions. It may be that teaching 'typical' gaze to autistic individuals leads to excessive cognitive load or discomfort. In parallel, explicit instruction of such an implicit social behavior may only serve to generate further differences *(e.g.,* unusually long fixations*)*. Future research should therefore investigate the *effects* of gaze differences on communication, as well as whether interventions might be hindering autistic individuals and/or *causing* additional challenges.

Conclusion

In summary, this review found that results from studies of live social gaze in adults and adolescents with high autistic traits are often mixed and scarce due to a lack of studies using ecologically valid paradigms. By analyzing results from both clinical and non-clinical studies,

we suggest that similar coarse-grained social orienting appears to be present in adults and adolescents with and without high autistic traits but fine-tuned social orienting potentially differs. Specifically, a negative relationship between ASC and gaze to eyes seems to be somewhat consistently found, although the strength and context of this relationship varies *considerably*. However, it is also found -quite consistently- that individuals with ASC or high autistic traits show modulation of their gaze according to contextual factors akin to controls. Two main interpretations are possible. First, the equivocal nature of the results may suggest that there simply aren't consistent differences in gaze behavior between autistic and allistic individuals, at least in samples matched in IQ and verbal abilities. Alternatively, the few differences found were confined to gaze to the eyes, suggesting that potential gaze differences in ASC are not a result of low social motivation, but rather reflect an aversion to the eyes. Future research should aim to strengthen the current evidence base by diversifying samples, increasing ecological validity, and examining more precise AOIs, notably the nose. In parallel, more work examining the specific *effects* of reduced gaze to the eyes on communicative efficiency should be conducted before considering interventional approaches.

Authorship contribution/confirmation statement

L.B conducted the initial search for eligible studies. Study inclusion was jointly discussed by both authors. L.B. wrote the first draft of this narrative review which was then iteratively improved via discussions with and edits from A.H.

REFERENCES

1. Mastergeorge AM, Kahathuduwa C, Blume J. Eye-Tracking in Infants and Young Children at Risk for Autism Spectrum Disorder: A Systematic Review of Visual Stimuli in Experimental Paradigms. *J Autism Dev Disord*. 2021;51(8):2578-2599. doi:10.1007/s10803-020-04731-w
2. Papagiannopoulou EA, Chitty KM, Hermens DF, Hickie IB, Lagopoulos J. A systematic review and meta-analysis of eye-tracking studies in children with autism spectrum disorders. *Soc Neurosci*. 2014;9(6):610-632. doi:10.1080/17470919.2014.934966
3. Guillon Q, Hadjikhani N, Baduel S, Rogé B. Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neurosci Biobehav Rev*. 2014;42:279-297. doi:10.1016/j.neubiorev.2014.03.013
4. Cañigueral R, Hamilton AF de C. Being watched: Effects of an audience on eye gaze and prosocial behaviour. *Acta Psychol (Amst)*. 2019;195:50-63. doi:10.1016/j.actpsy.2019.02.002
5. Laidlaw KEW, Foulsham T, Kuhn G, Kingstone A. Potential social interactions are important to social attention. *Proc Natl Acad Sci*. 2011;108(14):5548-5553. doi:10.1073/pnas.1017022108
6. Risko EF, Richardson DC, Kingstone A. Breaking the Fourth Wall of Cognitive Science: Real-World Social Attention and the Dual Function of Gaze. *Curr Dir Psychol Sci*. 2016;25(1):70-74. doi:10.1177/0963721415617806
7. Birmingham E, Bischof WF, Kingstone A. Saliency does not account for fixations to eyes within social scenes. *Vision Res*. 2009;49(24):2992-3000. doi:10.1016/j.visres.2009.09.014
8. Little AC, Jones BC, DeBruine LM. The many faces of research on face perception. *Philos Trans R Soc B Biol Sci*. 2011;366(1571):1634-1637. doi:10.1098/rstb.2010.0386
9. White D, Burton AM. Individual differences and the multidimensional nature of face perception. *Nat Rev Psychol*. Published online March 28, 2022:1-14. doi:10.1038/s44159-022-00041-3
10. Kendon A. Some functions of gaze-direction in social interaction. *Acta Psychol (Amst)*. 1967;26:22-63. doi:10.1016/0001-6918(67)90005-4
11. Gobel MS, Kim HS, Richardson DC. The dual function of social gaze. *Cognition*. 2015;136:359-364. doi:10.1016/j.cognition.2014.11.040
12. Ho S, Foulsham T, Kingstone A. Speaking and Listening with the Eyes: Gaze Signaling during Dyadic Interactions. *PLOS ONE*. 2015;10(8):e0136905. doi:10.1371/journal.pone.0136905
13. Degutyte Z, Astell A. The Role of Eye Gaze in Regulating Turn Taking in Conversations: A Systematized Review of Methods and Findings. *Front Psychol*. 2021;12. Accessed March 10, 2023. https://www.frontiersin.org/articles/10.3389/fpsyg.2021.616471
14. Hirvenkari L, Ruusuvuori J, Saarinen VM, Kivioja M, Peräkylä A, Hari R. Influence of Turn-Taking in a Two-Person Conversation on the Gaze of a Viewer. *PLOS ONE*. 2013;8(8):e71569. doi:10.1371/journal.pone.0071569
15. Wohltjen S, Wheatley T. Eye contact marks the rise and fall of shared attention in conversation. *Proc Natl Acad Sci*. 2021;118(37):e2106645118. doi:10.1073/pnas.2106645118
16. Kleinke CL. Gaze and eye contact: A research review. *Psychol Bull*. 1986;100(1):78-100. doi:10.1037/0033-2909.100.1.78
17. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)*. American Psychiatric Pub; 2013.
18. Gotham K, Risi S, Pickles A, Lord C. The Autism Diagnostic Observation Schedule: revised algorithms for improved diagnostic validity. *J Autism Dev Disord*. 2007;37(4):613-627. doi:10.1007/s10803-006-0280-1
19. Setien-Ramos I, Lugo-Marín J, Gisbert-Gustemps L, et al. Eye-Tracking Studies in Adults

with Autism Spectrum Disorder: A Systematic Review and Meta-analysis. *J Autism Dev Disord*. 2023;53(6):2430-2443. doi:10.1007/s10803-022-05524-z
20. Yi L, Wang Q, Song C, Han ZR. Hypo- or hyperarousal? The mechanisms underlying social information processing in autism. *Child Dev Perspect*. 2022;16(4):215-222. doi:10.1111/cdep.12466
21. Anderson DK, Maye MP, Lord C. Changes in Maladaptive Behaviors From Midchildhood to Young Adulthood in Autism Spectrum Disorder. *Am J Intellect Dev Disabil*. 2011;116(5):381-397. doi:10.1352/1944-7558-116.5.381
22. Chopik WJ, Oh J, Nuttall AK, Thakkar KN, Ingersoll B. Age differences in broader autism phenotype traits from young adulthood to older adulthood. *Autism Res Off J Int Soc Autism Res*. 2021;14(7):1456-1471. doi:10.1002/aur.2504
23. Prigge MBD, Bigler ED, Lange N, et al. Longitudinal Stability of Intellectual Functioning in Autism Spectrum Disorder: From Age 3 Through Mid-adulthood. *J Autism Dev Disord*. Published online October 22, 2021. doi:10.1007/s10803-021-05227-x
24. Nakano T, Tanaka K, Endo Y, et al. Atypical gaze patterns in children and adults with autism spectrum disorders dissociated from developmental changes in gaze behaviour. *Proc R Soc B Biol Sci*. 2010;277(1696):2935-2943. doi:10.1098/rspb.2010.0587
25. Chevallier C, Kohls G, Troiani V, Brodkin ES, Schultz RT. The social motivation theory of autism. *Trends Cogn Sci*. 2012;16(4):231-239. doi:10.1016/j.tics.2012.02.007
26. Kliemann D, Dziobek I, Hatri A, Baudewig J, Heekeren HR. The Role of the Amygdala in Atypical Gaze on Emotional Faces in Autism Spectrum Disorders. *J Neurosci*. 2012;32(28):9469-9476. doi:10.1523/JNEUROSCI.5294-11.2012
27. Bolis D, Balsters J, Wenderoth N, Becchio C, Schilbach L. Beyond Autism: Introducing the Dialectical Misattunement Hypothesis and a Bayesian Account of Intersubjectivity. *Psychopathology*. 2017;50(6):355-372. doi:10.1159/000484353
28. Hessels RS, Holleman GA, Cornelissen THW, Hooge ITC, Kemner C. Eye contact takes two – autistic and social anxiety traits predict gaze behavior in dyadic interaction: *J Exp Psychopathol*. Published online June 30, 2018. doi:10.5127/jep.062917
29. Yarbus AL. Eye Movements During Fixation on Stationary Objects. In: Yarbus AL, ed. *Eye Movements and Vision*. Springer US; 1967:103-127. doi:10.1007/978-1-4899-5379-7_4
30. Carter BT, Luke SG. Best practices in eye tracking research. *Int J Psychophysiol*. 2020;155:49-62. doi:10.1016/j.ijpsycho.2020.05.010
31. Plużyczka M. The first hundred years: A history of eye tracking as a research method. *Appl Linguist Pap*. 2018;(25/4):101-116.
32. Harezlak K, Kasprowski P. Application of eye tracking in medicine: A survey, research issues and challenges. *Comput Med Imaging Graph Off J Comput Med Imaging Soc*. 2018;65:176-190. doi:10.1016/j.compmedimag.2017.04.006
33. Klaib AF, Alsrehin NO, Melhem WY, Bashtawi HO, Magableh AA. Eye tracking algorithms, techniques, tools, and applications with an emphasis on machine learning and Internet of Things technologies. *Expert Syst Appl*. 2021;166:114037. doi:10.1016/j.eswa.2020.114037
34. Baltrušaitis T, Zadeh A, Lim YC, Morency LP. OpenFace 2.0: Facial Behavior Analysis Toolkit. Published online 2018.
35. Jarick M, Bencic R. Eye Contact Is a Two-Way Street: Arousal Is Elicited by the Sending and Receiving of Eye Gaze Information. *Front Psychol*. 2019;10. Accessed September 24, 2023. https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01262
36. Frazier TW, Strauss M, Klingemier EW, et al. A Meta-Analysis of Gaze Differences to Social and Nonsocial Information Between Individuals With and Without Autism. *J Am Acad Child Adolesc Psychiatry*. 2017;56(7):546-555. doi:10.1016/j.jaac.2017.05.005
37. Cuve HC, Gao Y, Fuse A. Is it avoidance or hypoarousal? A systematic review of emotion recognition, eye-tracking, and psychophysiological studies in young adults with autism spectrum conditions. *Res Autism Spectr Disord*. 2018;55:1-13.

doi:10.1016/j.rasd.2018.07.002
38. Riddiford JA, Enticott PG, Lavale A, Gurvich C. Gaze and social functioning associations in autism spectrum disorder: A systematic review and meta-analysis. *Autism Res*. 2022;15(8):1380-1446. doi:10.1002/aur.2729
39. Laskowitz S, Griffin JW, Geier CF, Scherf KS. Cracking the Code of Live Human Social Interactions in Autism: A Review of the Eye-Tracking Literature. In: *Understanding Social Behavior in Dyadic and Small Group Interactions*. PMLR; 2022:242-264. Accessed January 30, 2023. https://proceedings.mlr.press/v173/laskowitz22a.html
40. Ruzich E, Allison C, Smith P, et al. Measuring autistic traits in the general population: a systematic review of the Autism-Spectrum Quotient (AQ) in a nonclinical population sample of 6,900 typical adult males and females. *Mol Autism*. 2015;6(1):2. doi:10.1186/2040-2392-6-2
41. Baron-Cohen S, Wheelwright S, Skinner R, Martin J, Clubley E. The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Malesand Females, Scientists and Mathematicians. *J Autism Dev Disord*. 2001;31(1):5-17. doi:10.1023/A:1005653411471
42. Freeth M, Foulsham T, Kingstone A. What Affects Social Attention? Social Presence, Eye Contact and Autistic Traits. *PLOS ONE*. 2013;8(1):e53286. doi:10.1371/journal.pone.0053286
43. von dem Hagen EAH, Bright N. High autistic trait individuals do not modulate gaze behaviour in response to social presence but look away more when actively engaged in an interaction. *Autism Res*. 2017;10(2):359-368. doi:10.1002/aur.1666
44. Mansour H, Kuhn G. Studying “natural” eye movements in an “unnatural” social environment: The influence of social activity, framing, and sub-clinical traits on gaze aversion: *Q J Exp Psychol*. Published online January 12, 2019. doi:10.1177/1747021818819094
45. Vabalas A, Freeth M. Brief Report: Patterns of Eye Movements in Face to Face Conversation are Associated with Autistic Traits: Evidence from a Student Sample. *J Autism Dev Disord*. 2016;46(1):305-314. doi:10.1007/s10803-015-2546-y
46. Wilkinson D. EFFECTS OF PARTICIPANT’S ROLE AND NARRATIVE TOPIC ON VISUAL ATTENTION IN ADULTS WITH AUTISM DURING A STRUCTURED INTERACTION. Published May 30, 2014. Accessed May 4, 2022. http://d-scholarship.pitt.edu/20762/
47. Auyeung B, Lombardo MV, Heinrichs M, et al. Oxytocin increases eye contact during a real-time, naturalistic social interaction in males with and without autism. *Transl Psychiatry*. 2015;5(2):e507-e507. doi:10.1038/tp.2014.146
48. Yoshikawa Y, Kumazaki H, Matsumoto Y, Miyao M, Kikuchi M, Ishiguro H. Relaxing Gaze Aversion of Adolescents With Autism Spectrum Disorder in Consecutive Conversations With Human and Android Robot—A Preliminary Study. *Front Psychiatry*. 2019;10. Accessed May 4, 2022. https://www.frontiersin.org/article/10.3389/fpsyt.2019.00370
49. Cañigueral R, Ward JA, Hamilton AF de C. Effects of being watched on eye gaze and facial displays of typical and autistic individuals during conversation. *Autism*. 2021;25(1):210-226. doi:10.1177/1362361320951691
50. Freeth M, Bugembe P. Social partner gaze direction and conversational phase; factors affecting social attention during face-to-face conversations in autistic adults? *Autism*. 2019;23(2):503-513. doi:10.1177/1362361318756786
51. Grossman RB, Zane E, Mertens J, Mitchell T. Facetime vs. Screentime: Gaze Patterns to Live and Video Social Stimuli in Adolescents with ASD. *Sci Rep*. 2019;9(1):12643. doi:10.1038/s41598-019-49039-7
52. Barzy M, Ferguson HJ, Williams DM. Perspective influences eye movements during real-life conversation: Mentalising about self versus others in autism. *Autism*. 2020;24(8):2153-2165. doi:10.1177/1362361320936820

53. Clin E, Kissine M. Neurotypical, but not autistic, adults might experience distress when looking at someone avoiding eye contact: A live face-to-face paradigm. *Autism Int J Res Pract*. 2023;27(7):1949-1959. doi:10.1177/13623613221148553
54. Hanley M, Riby DM, Carty C, Melaugh McAteer A, Kennedy A, McPhillips M. The use of eye-tracking to explore social difficulties in cognitively able students with autism spectrum disorder: A pilot investigation. *Autism*. 2015;19(7):868-873. doi:10.1177/1362361315580767
55. Vertegaal R, Slagter R, van der Veer G, Nijholt A. Eye gaze patterns in conversations: there is more to conversational agents than meets the eyes. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '01. Association for Computing Machinery; 2001:301-308. doi:10.1145/365024.365119
56. Priscott T, Allen RA. Human capital neurodiversity: an examination of stereotype threat anticipation. *Empl Relat Int J*. 2021;43(5):1067-1082. doi:10.1108/ER-06-2020-0304
57. Lahiri U, Bekele E, Dohrmann E, Warren Z, Sarkar N. A Physiologically Informed Virtual Reality Based Social Communication System for Individuals with Autism. *J Autism Dev Disord*. 2015;45(4):919-931. doi:10.1007/s10803-014-2240-5
58. Norbury CF, Brock J, Cragg L, Einav S, Griffiths H, Nation K. Eye-movement patterns are associated with communicative competence in autistic spectrum disorders. *J Child Psychol Psychiatry*. 2009;50(7):834-842. doi:10.1111/j.1469-7610.2009.02073.x
59. Rogers SL, Speelman CP, Guidetti O, Longmuir M. Using dual eye tracking to uncover personal gaze patterns during social interaction. *Sci Rep*. 2018;8(1):4271. doi:10.1038/s41598-018-22726-7
60. Crompton CJ, Ropar D, Evans-Williams CV, Flynn EG, Fletcher-Watson S. Autistic peer-to-peer information transfer is highly effective. *Autism*. 2020;24(7):1704-1712. doi:10.1177/1362361320919286