

Visual Attention in Real-World Conversation: Gaze Patterns Are Modulated by Communication and Group Size

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Gaze behavior both initiates and maintains conversations, playing a crucial role in real-world collaboration. Hitherto, most findings on social attention stem from research using pictures of faces in the laboratory, however, attention operates differently in the real world. Thus, we know little of how gaze behavior operates in naturalistic interactions. To bridge this gap, we applied mobile eye-tracking to investigate the gaze patterns present in naturalistic conversations. Specifically, we examined gaze behavior of participants in a group of two or five, either sitting together in silence, or engaging in a conversation, in which they took turns either listening or speaking to each other. Results show that participants looked more frequently towards others when the group was communicating compared to when remaining silent, and that they looked at others more frequently when listening compared to when speaking. Furthermore, being part of a dyad led to more social attention being afforded during conversation compared to the group situation, regardless of whether subjects were listening or speaking. Meanwhile, when sitting in silence subjects showed less social gazing in a dyad than in a group of five. Our results provide qualitative

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and quantitative insights into the patterns of visual attention during dynamic naturalistic conversations.

INTRODUCTION

Whether examining expert-to-novice knowledge transfer (e.g., Moser, 2017), a leader-follower exchange (e.g., Rowold & Laukamp, 2009), a routine transaction between customer and salesperson (Elizur, 1987), a negotiation between two or more partners (e.g., Schei, Rognes, & Mykland, 2006), an employee interview (e.g., Bye et al., 2010; Chen & Lin, 2013), performance appraisal (e.g., Ilgen & Davis, 2000), human resource development (e.g., Poell, Van Dam, & Van den Berg, 2004) and instruction (e.g., De Corte, 2004), a confidential and potentially vital patient to practitioner consultation, or the simple verbal exchange that occurs when collaboration requires coordination (e.g., Sonnentag, 2000), they all share one central point: they revolve around successful conversation, a cornerstone of both social and professional life. How we behave visually is a crucial factor, as the way we gaze both induces conversation and shapes the flow of words between listening and speaking (Ho, Foulsham, & Kingstone, 2015). While there are findings on interpersonal gaze behavior in a laboratory setting, recent research indicates that visual attention operates differently in real-world interactions (Risko, Richardson, & Kingstone, 2016). Central to applied psychology is a desire to understand and predict cognition and behavior as it is displayed within complex real-world situations. However, laboratory-based experiments into social gaze, employing artificial stimuli and fixed response options, inevitably result in findings that lack ecological validity when translated into applied fields (Vanhove & Harms, 2015). This is the case particularly due to gaze behavior's social nature, relying as it does on the normative demands of a social situation, and adapting dynamically to the affordances within social communication (Wu, Bischof, & Kingstone, 2013). To redress this gap in our current understanding, this study aims to paint a first picture of how visual attention operates in the dynamic flow of a naturalistic conversation. To elucidate this, we measured gaze behavior using mobile eye-tracking in a staged interaction. In doing so we shed light on how social gaze behavior adapts to the dynamic affordances of an everyday conversation, and thereby sketch out the attentional anatomy of this kind of human interaction.

Gaze Behavior in Social Interaction

Directing our gaze towards others is inalienably crucial to the functioning of social interaction (Grossmann, 2017). Mere observation of others allows us

to collect a wide range of information that shapes the interaction (Maran, Futner, Liegl, Kraus, & Sachse, 2019) and the conversational partners' mental states (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Senju & Johnson, 2009). In fact, a speaker's gaze, directed at the receiver, is integral to the decoding process, and thus the comprehension, of the spoken message (Barenholtz, Mavica, & Lewkowicz, 2016; Holler et al., 2014; Schober & Clark, 1989). Vice versa, being observed by others enhances cooperation (Bateson, Nettle, & Roberts, 2006; Ekström, 2012; Maran, Furtner, Kraus, Liegl, & Jones, 2019) and reduces dishonesty (Nettle, Nott, & Bateson, 2012). Further, eye contact can promote prosocial behaviors (Ekström, 2012) and even stimulates behavioral synchronization (Prinsen et al., 2017). Therefore, the role of social gazing in everyday interactions extends beyond the gathering of information from our dialog partner. In fact, it is clear that human eyes have evolved especially to facilitate social functioning (Kobayashi & Kohshima, 1997). They possess a unique, horizontally elongated outline, as well as a high portion of white sclera, the highest of any primate species (Kobayashi & Kohshima, 1997), both of which combine to let others see clearly where our gaze falls (Gobel, Kim, & Richardson, 2015; Khalid, Deska, & Hugenberg, 2016). In short, our eyes act not merely as receivers of information, but also serve a vital function as signalers of information.

These twofold functions are fundamental to collaboration, and clearly delineate the crucial role social gaze behavior holds for a range of situations that fall into the purview of applied psychology, such as workplace collaboration and leadership, customer interaction, or knowledge sharing (e.g., Maran, Futner, Liegl, et al., 2019). Each of these is shaped by nonverbal communication (e.g., Hall, Horgan, & Murphy, 2019) and, at the core, by social eye signaling (Bonaccio, O'Reilly, O'Sullivan, & Chiocchio, 2016). To conclude, gaze behavior acts not only as a sensory channel to the external, to capture visual information, but operates too as a social signal. In doing so, it shapes human interaction, from initiation to outcomes. The examination of this latter facet, however, has all too often either been flawed, or completely neglected.

From Lab to Real World: Visual Attention Shaped by Social Interaction

Compared to laboratory studies, eye movements operate differently in real-life environments (Lappi, 2016) and are especially sensitive to social presence (Freeth, Foulsham, & Kingstone, 2013). Why is this? Because gaze has a dual function, as outlined in the previous section. While obviously serving the function of gathering information from our sensory environment, it simultaneously acts as a potent channel of communication (Risko et al., 2016),

constituting, in fact, a central pillar of social cognition (Emery, 2000; Senju & Johnson, 2009). Unfortunately, and very much in contrast to naturalistic designs, most research on social attention is based on paradigms presenting isolated social cues (Risko et al., 2016). Divergences from naturalistic gaze behavior, therefore, arise in laboratory settings because the dual function of gaze is not activated, given that the social signaling function of eye behavior present in reciprocal conversations remains absent in those settings (Risko et al., 2016). In short, in isolation paradigms, subjects look at social stimuli but the social stimuli don't look back.

An emerging stream of research has begun to describe these disparities (Foulsham, Walker, & Kingstone, 2011; Risko et al., 2016). For example, in real life, people often avoid looking at a person whom they do not know when both are sitting in the same room (Laidlaw, Foulsham, Kuhn, & Kingstone, 2011) but would nevertheless follow another's gaze towards an object (Gallup, Chong, & Couzin, 2012). When people are viewing videos of others, they modify their gaze behavior depending on whether they are kept in the belief that the person they are gazing at can see where they looked at later on (Gobel et al., 2015). These examples illustrate the nebulous state of research regarding how social attention operates in real-world conversations. This is a poor state of affairs considering that social gaze is a core constituent of social interaction, which in turn makes possible a panoply of situations relevant to applied psychology, including customer transactions (Elizur, 1987), expert knowledge transfers (e.g., Moser, 2017), or negotiation between two or more partners (e.g., Schei et al., 2006).

Naturalistic study designs, on the other hand, account for the dual function of eye behavior, and thereby offer a first insight into the real-world dynamics of social attention. For example, while there are strong interindividual differences in what people prefer to look at within the facial area (Rogers, Spelman, Guidetti, & Longmuir, 2018), visual attention towards others is also highly reliant on the dynamic affordances of the situation. For example, when eating together at a table, people show an increased tendency to gaze at the other person (Wu et al., 2013), but look the other way when someone begins to chew (Wu, Bischof, & Kingstone, 2014). Beyond such specific situations, normative rules are highly differentiated in a host of social situations, governing, for instance, when it is suitable to look at or away from others during the dynamic flow of communication. For example, gaze functions as a signal for an upcoming switch in communication roles, as speakers end their speaking turn with direct gaze at the listener and the counterpart begins to speak with averted gaze (Ho et al., 2015). Being gazed at even acts similarly to hearing one's name called (Kampe, Frith, & Frith, 2003), drawing attention to the person gazing and creating immediate involvement (Senju & Johnson, 2009). And finally, the maintenance of a reciprocal conversation is

heavily reliant on appropriate gaze behavior, which both supports a mutual understanding of the spoken message and clearly identifies the recipient of the sender's message (Grossmann, 2017; Risko et al., 2016). These factors should result in increased visual attention, by subjects interacting with others, towards those others.

Hypothesis 1: People taking part in a conversation direct their gaze towards those participating in the conversation more frequently when communication is taking place, as opposed to when all participants are silent.

Once a conversation is initiated, gaze behavior supports the natural flow of turn taking between listening and speaking (Ho et al., 2015). In this vein, we hypothesize participants to engage in more social gazing when they are listening to others compared to when they are speaking themselves (e.g., Argyle & Cook, 1976; Freeth & Bugembe, 2018). Once an interaction has begun, listening demands increased social signaling of personal engagement, as, when listening, people might have no other channel to signal their continued interest in and attention to the speaker.

Hypothesis 2: People taking part in a conversation direct their gaze towards those participating in the conversation more frequently while listening, compared to when they themselves are speaking.

In sum, as soon as eye behavior occurs under social presence, it becomes conditional upon the social rules of the situation (e.g., Wu et al., 2013, 2014), and renders itself crucial for initiating, maintaining, and regulating social communication.

Visual Attention Moderated by Group Size

The dyad is the most common form of interactive configuration (Dunbar, Duncan, & Nettle, 1995), offering a social setting for intimate exchange (Taylor, De Soto, & Lieb, 1979). However, we often find ourselves in situations characterized by close proximity to multiple strangers in groups of differing sizes, for example when commuting by train or engaging in a meeting at work. Research suggests an upper limit of four to five for concurrent conversation (Dunbar et al., 1995; Fay, Garrod, & Carletta, 2000). In fact, previous findings have also shown that social presence affects visual behavior, which adapts to increases in social presence depending on the size of a group (Gallup et al., 2012). Indeed, research shows people regulating proximity and distance with social gaze, and generally minimizing eye contact with others when in a crowd of strangers (Fried & DeFazio, 1974; Zuckerman, Miserandino, & Bernieri, 1983). Even the transmission of visual attention in

terms of joint attention is dependent on social factors such as proximity to others, the dynamic mapping of the social environment, and, most notably, group size (Gallup, Hale et al., 2012). To conclude, the size of the conversational group may shape how we communicate with others, and, more specifically, the way we employ gaze signaling to do so. During dyadic interactions, which represent the most common and intimate form of social encounters (Dunbar et al., 1995), the onus of responsibility to signal adequate involvement lies solely on one single participant. By contrast, when more people interact with each other, if someone is talking, more than one person is generally expected to support the conversation through adequate gaze signaling. This renders each individual's involvement, or at least their active effort to signal involvement, susceptible to social loafing (Karau & Williams, 1993; Meyer, Schermuly, & Kauffeld, 2016). For this reason, we expect an increased display of social visual attention in the dyadic setting.

Hypothesis 3: People taking part in a conversation direct their gaze towards those participating in the conversation more frequently in a dyadic situation compared to a group situation.

In summary, this study investigates how naturalistic visual attention adapts to the dynamic flow of a conversation in real life. In testing our hypothesis, we chose a method recent research has increasingly come to recognize for its utility in the examination of visual attention processes, namely mobile eye-tracking (Freeth & Bugembe, 2018; Macdonald & Tatler, 2018; Rogers et al., 2018). Indeed, the increasing application of this novel technology has opened up possibilities for examining the effects of gaze behavior in applied contexts, such as traffic and occupational psychology, as mobile eye-tracking is particularly suited to the analysis of eye signaling. Therefore, we hope not merely to test our hypotheses, but also to approach the delineation of social visual attention during naturalistic interaction in a more explorative manner, as eye-tracking permits a host of quantitative insights into the dynamics of visual attention. First and foremost, this method permits reliable measurements of gaze behavior during naturalistic social interactions (see Chukoskie et al., 2018 and Chong et al., 2017 for alternative methodological approaches for assessing naturalistic gaze behavior).

In our experiment, the social encounter was set up so that subjects were first sitting together silently, and then engaged in a verbal conversation. We chose a naturalistic design to compare an interacting dyad or group of five to investigate how social attention varies with group size. During the experiment, we maintained a stable structure of the stages of the interaction (silence, speaking, listening) to provide as much experimental control as possible without hampering the free expression of dialogue.

METHODS

The chosen paradigm reflected this study's aim of investigating how participants' gaze behavior adapted to different stages of a conversation and varying social presence during a real-world conversation. We chose a naturalistic setting with either two or five people sitting together in a circular arrangement (one of them being the actual subject), facing each other, while either sitting in silence or conversing on everyday topics (see Figure 1A and B). Participants were unaware the others in the conversation were confederates using predefined statements. Standardized questions were given to start a natural conversation about everyday life topics and problems relating to their field of occupation. The order, content, and length of confederates' answers were kept constant for all participants. Taken together, this design ensured a naturalistic, yet experimentally controlled setting. To measure visual attention in a dynamic social situation, we assessed participants' gaze behavior towards the confederates throughout the whole experiment using a mobile eye-tracking device (Tobii Pro Glasses 2 with a sampling rate 100 Hz and a spatial accuracy of 0.63 degrees at a distance of 1.5 meters). The subject was told that the device would merely record audio-visual data for subsequent investigations. After the final debrief, none of the participants reported having

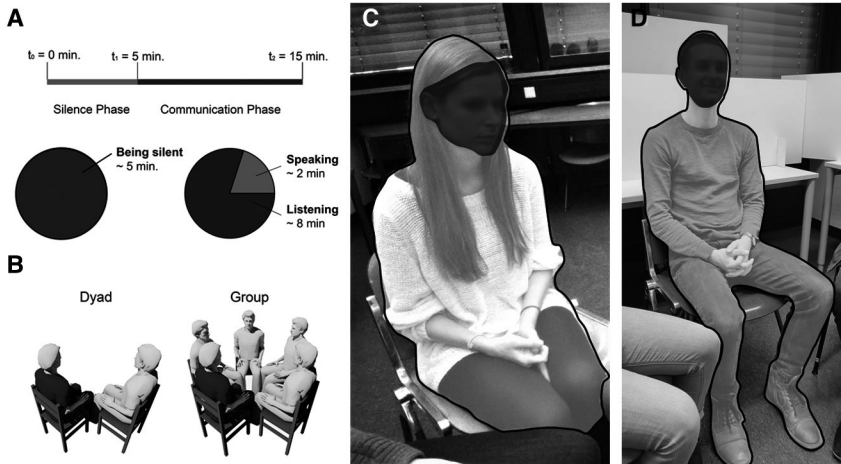


FIGURE 1. Illustration of the experimental setup and coding scheme. Subjects first sat together in silence and were then instructed to engage in conversation with each other (A), either in a dyadic or a group setting (B). Gaze behavior was coded according to predefined regions of interest (face, body, room). Social gaze was quantified as the relative number of gazes towards the social regions of the confederates' face (dark area) and body (light area) within the visual field (C, D).

noticed the device capturing their gaze, or that the other participants were actually confederates.

This design, therefore, results in three *stages of interaction* (*silence, listening, speaking*) and two *conditions of social presence*: *dyad* (i.e., one confederate) and *group* (i.e., four confederates). For the data analyses we further differentiate the interaction stages in two *interaction types*, described as *silence* and *communication*, with the latter one combining both the listening and speaking phase, and in two *communication roles* (*listening, speaking*).

Sample

Subjects were healthy adults, $N = 37$ ($n = 25$ being female). The age of the subjects ranged from 18 to 38 years, $M = 22.08$, $SD = 5.11$. None of the participants indicated suffering from a diagnosed psychiatric disease, being under the influence of psychoactive substances or psychopharmacologic treatment, or having suffered severe head injuries over the course of their lives. All had normal or corrected-to-normal visual acuity. The study was conducted in line with the guidelines of the Ethics Committee of the University of Innsbruck and participants provided informed consent.

Event Coding Criteria for Eye-Tracking Recordings

Classifications of stationary eye-tracking studies do not entirely portray eye behavior as it naturally occurs in the real world (Lappi, 2016), instead pre-process the data measured. To gain insights closer to the real-world dynamics of gaze, we focused on raw, unprocessed gaze locations within social regions of the visual field. We defined gaze locations based on the raw measurements depicted on participants' actual visual field as indicated by video recording of the mobile eye-tracking device.

Social attention was operationalized as the number of gazes *entering* a social region within the visual field, that is, comprising confederates' faces and bodies (see Figure 1C and D; our main analyses focus on the attention on both regions, for results on social gazes towards faces see the Supplementary Information online). All gaze points outside of the social region were classified as *room*. Since evidence shows stable interindividual differences regarding preferential focus on mouth or eye regions (Rogers et al., 2018), the whole face represented the smallest region of interest.

Gaze behavior was coded manually frame by frame based on audio-visual and gaze recordings using Tobii Pro Glasses Analyzer. The software allows watching the footage in real time while displaying a superimposed circle depicting the calculated gaze position and defining the beginning and the end of each gaze event. All consecutive gaze locations that were not directed at

the predefined regions of interest (face, body, room) for at least 240 ms were removed. This threshold represents a conservative estimate of a time interval that is necessary for extracting adequate information (Lappi, 2016; Salthouse & Ellis, 1980; Westheimer, 1954). Based on this criterion, 11 percent of the data were removed. For additional information on the coding procedure and on the reasoning behind choosing the number of gaze events as our dependent variable please see the Supplementary Information.

All data and analysis scripts are publicly available on the Open Science Framework (osf.io/zcsb7).

Procedure

Before starting the experimental procedure, the mobile eye-tracking device was fitted to and calibrated for each participant. As mentioned above, subjects were informed that the device would be only used to gather audio-visual information about the other supposedly naive participants so that the experimenters could listen to the conversation afterwards. The other subjects were confederates who all had predefined verbal scripts, and had previously been trained to offer equal amounts of eye contact to all subjects, to act calmly, and to avoid exaggerated emotional display. They entered the room after the calibration was done and sat next to the participant within the typical social space radius, that is, 1.22 m to 3.66 m (Hall, 1966), in which most social encounters take place (see Figure 1B). The order of attending a group and dyadic interaction was counterbalanced across all participants (counterbalancing the conditions had no impact on participants' gaze behavior, see the Supplementary Information for the analyses). In order to avoid familiarity affecting the gaze behavior, the confederate who partook in the dyad was not part of the group interaction.

Since our research design aimed to encompass the different stages of an interaction—that is, a silence and a communication phase in which participants would alternately listen or speak to one another—we systematically varied these interaction types (see Figure 1A). Subjects were first told to remain silent for five minutes, before a conversation would take place. At the start of the conversational phase, the experimenter asked subjects to give statements about an everyday topic. Each round, every subject had to consecutively give one statement (in one utterance) to the other subjects. Communication went on for four rounds with a different topic (e.g., last weekend's activities, last places visited in the local city). This meant that each subject contributed four statements overall. In the dyadic condition, instead of taking turns with equal numbers of statements, the confederate gave four consecutive statements about each topic to maintain a ratio of listening to speaking similar as in the group conversation. Both the dyadic and group conversation lasted around

10 minutes. The prescribed speech topics allowed for the development of a fluent and naturalistic conversation, while the constant order, content, and length of confederates' answers provided considerable experimental control.

RESULTS

To test our hypotheses, we conducted Bayesian and frequentist multiple planned *t*-tests and analyses of variance for repeated-measures designs. In case of deviance from sphericity, tested by Mauchly's test, degrees of freedom were corrected using the Greenhouse-Geisser correction. All reported *p*-values are two tailed. Alpha levels were set at 0.05. Effect sizes are reported by partial eta squared η_p^2 [0.01 = small; 0.06 = medium; 0.14 = large] for analyses of variance and by Cohen's *d* [0.3 = small; 0.5 = medium; 0.8 = large] for *t*-tests. Bayes inferential procedures were applied for each hypothesis testing to quantify the relative likelihood of a hypothesis compared to the null hypothesis (Wagenmakers et al., 2018). Bayes factors were reported as BF_{10} (1 to 3 = anecdotal evidence for the proposed hypothesis; 3 to 10 = moderate evidence; 10 to 30 = strong evidence; 30 to 100 = very strong evidence; >100 = extreme evidence; Lee & Wagenmakers, 2014). Data analyses were conducted using SPSS (Version 24) and JASP (Version 0.8.6; JASP Team 2018).

Visual Attention During Stages of Interaction

In order to test the differences in gaze behavior between the experimental stages, we conducted a repeated measures ANOVA, comparing all three stages of interaction. We found the rate of social attention to be markedly different depending on whether participants were silent, listening or speaking ($F_{2,72} = 119.32$, $p < .001$, $\eta_p^2 = 0.77$, $BF_{10} = 7.73e+21$). Zooming into the results over all stages of interaction, planned comparisons revealed that participants displayed a lower gaze count in silence compared to both the listening phase (with a difference of -28.3 percent; $SE = 2.2\%$; 35 of 37 participants following this trend), Bonferroni-adjusted $p < .001$, and the speaking phase (with a difference of -6.3%; $SE = 1.8\%$; 25 of 37 participants; see Figure 2), Bonferroni-adjusted $p = .004$. These findings lend support to our first hypothesis, showing that participants look more frequently towards others while conversing with each other than when sitting in silence.

Furthermore, the comparisons revealed a noticeable difference in how much social attention was displayed while listening (80.4%, $SE = 2.1\%$) compared to speaking (58.3%, $SE = 1.7\%$), with a mean difference of 22.1 percent ($SE = 1.7\%$, 36 of 37 participants; Figure 3), Bonferroni-adjusted $p < .001$. These latter results favor our second hypothesis, regarding increased counts of social gaze points being displayed while listening as compared to speaking.

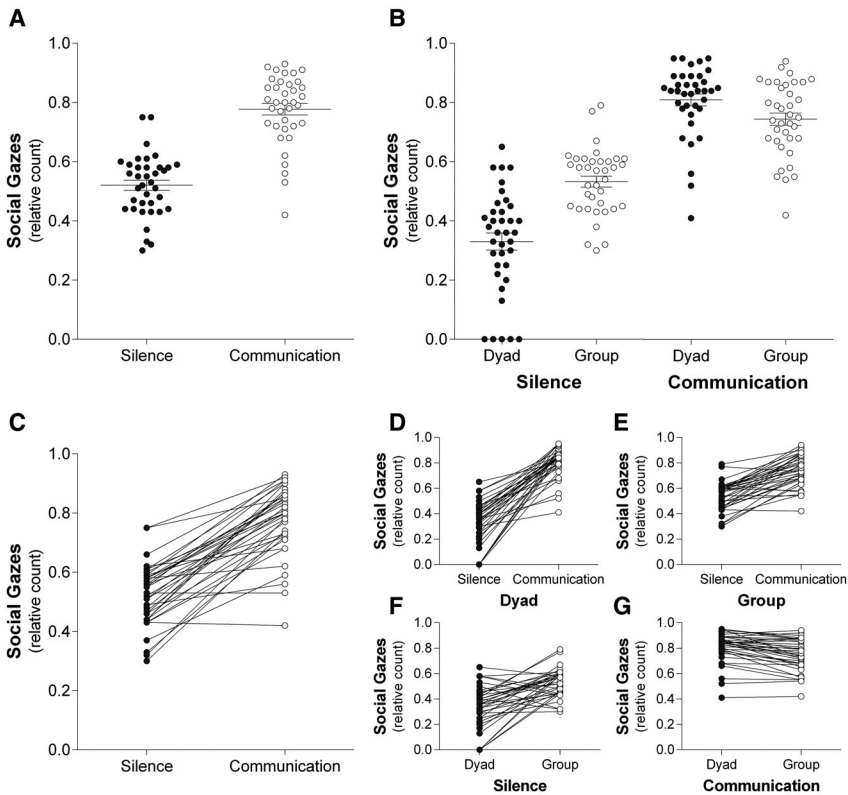


FIGURE 2. Overall distribution and adaptations of social attention for each participant ($n = 37$) while interacting (silence and active communication) for the one person and four people conditions (dyad and group). Social attention is displayed as a percentage of total number of gazes. Data points for silence and conversation phases (A, C), as well as comparisons for group sizes (B, D, E, F, G).

To provide a direct test of our first hypothesis on social attention differences between the silence and conversation condition, we performed a further t -test. Results confirmed our first hypothesis, that subjects looked at others considerably more often when they were actively communicating (i.e., the listening and speaking phases taken together, 77.7% of their gazes, $SE = 1.9\%$) compared to when being silent (52.1%, $SE = 1.7\%$; $t_{36} = -12.39$, Bonferroni-adjusted $p < .001$, $d = -2.04$, $BF_{10} = 4.51e+11$; 35 of 37 participants; Figure 2).

Visual Attention in a Dyad and a Group of Five

In addition to the dynamic adaptations of visual attention caused by a switch between different stages of the interaction, social presence altered

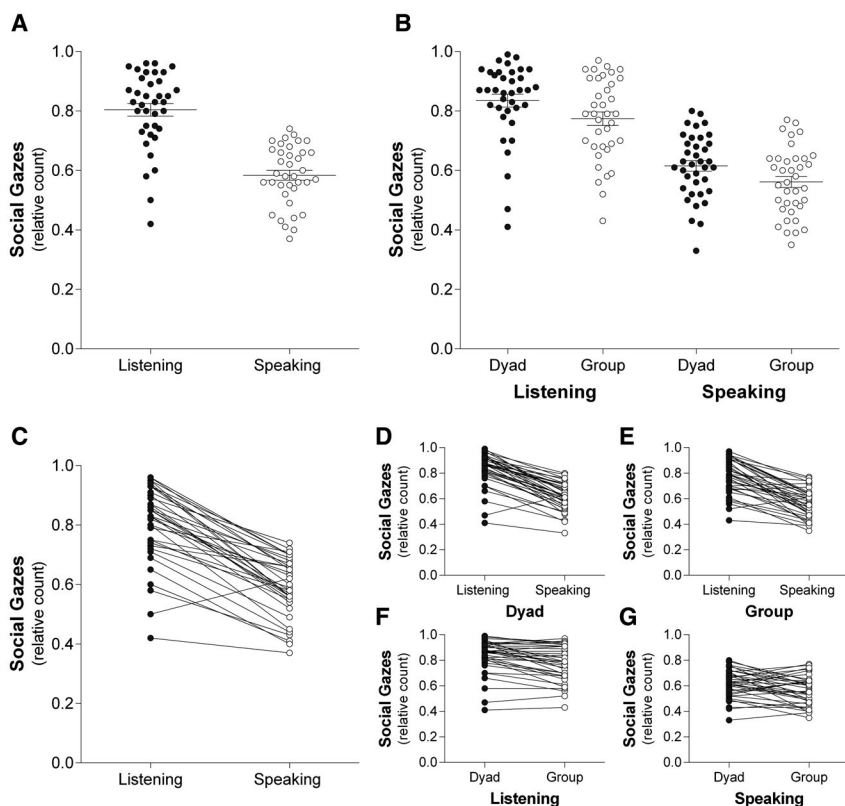


FIGURE 3. Overall distribution and adaptations of social attention for each participant ($n = 37$) while actively conversing (listening and speaking) for the one person and four people conditions (dyad and group). Social attention is displayed as a percentage of total number of gazes. Data points for listening and speaking (A, C), as well as comparisons for group sizes (B, D, E, F, G).

participants' gaze behavior across the types of interaction (silence, communication), as revealed by a 2×2 repeated measures ANOVA. Supporting Hypothesis 3, a main effect for social presence showed social gazing increased in the dyadic condition compared to the interaction in a group of five ($F_{1,36} = 13.72, p < .001, \eta_p^2 = 0.28, BF_{10} = 0.89$; 33 of 37 participants following this trend). Participants displayed more social attention when interacting with one person (79.4%, $SE = 2.0\%$) as compared to interacting with four (70.2%, $SE = 1.8\%$; $t_{36} = 8.09$, Bonferroni-adjusted $p < .001, d = 1.33, BF_{10} = 9.01e+6$; 34 of 37; Figure 2). These findings lend first evidence to our third hypothesis. Interestingly, we found an interaction effect for social presence

and the interaction type ($F_{1,36} = 57.16, p < .001, \eta_p^2 = 0.61, BF_{10} = 1.34e+7$). Participants gazed less towards others when sitting in silence with one person (33.1%, $SE = 2.9\%$), as compared to when sitting in silence with four people (53.3%, $SE = 1.8\%$; $t_{36} = -5.88$, Bonferroni-adjusted $p < .001, d = -0.97, BF_{10} = 16930.59$; 31 of 37 participants; Figure 2). However, when actively communicating, this pattern was reversed and more social attention was shown towards one person (80.9%; $SE = 2.0\%$) than towards four (74.5%, $SE = 2.1\%$; $t_{36} = 5.54$, Bonferroni-adjusted $p < .001, d = 0.91, BF_{10} = 6390.40$; 30 of 37 participants; Figure 2).

Next, we looked into how social gaze within the conversation, that is, while participants listened or spoke to their counterparts, was affected by group size. A repeated measures ANOVA showed a main effect for social presence ($F_{1,36} = 22.39, p < .001, \eta_p^2 = 0.38, BF_{10} = 2.32$), but without any interaction between the role (i.e., while listening or speaking) within the conversation and social presence ($F_{1,36} = 0.13, p = 0.719, BF_{10} = 0.25$). Subjects showed more social attention when listening in the dyad (83.5%, $SE = 2.2\%$) than in the group (77.4%, $SE = 2.3\%$; $t_{36} = 4.92$, Bonferroni-adjusted $p < .001, d = 0.81, BF_{10} = 1108.51$; 27 of 37 participants; Figure 3). When speaking, the rate decreased to 61.5 percent ($SE = 1.8\%$) in the dyad and 56.1 percent ($SE = 1.9\%$) in the group, ($t_{36} = 2.887$, Bonferroni-adjusted $p = 0.039, d = 0.48, BF_{10} = 6.027$; 24 of 37 participants; Figure 3). This finding suggests that participants paid more attention towards their counterparts when conversing in a dyad, regardless of whether they listened or spoke to others. This is well in line with our findings, on the effects of social presence on gaze behavior for the communication versus silence conditions.

Finally, considering both social presence (dyad, group) and all stages of the interaction (silence, listening, speaking), a 2×3 repeated measures ANOVA again revealed a small and barely significant main effect for social presence ($F_{1,36} = 4.14, p = 0.049, \eta_p^2 = 0.10, BF_{10} = 0.26$; Figure 4). Participants looked more towards others when sitting in a dyad as compared to a group, which is surprising given the presence of more people to divide one's gaze between when interacting with four counterparts. Furthermore, as previously found for the interaction type (i.e., silence and communication), analyses again showed an interaction effect ($F_{1,41,50.92} = 42.32, p < .001, \eta_p^2 = 0.54, BF_{10} = 7.19e+9$). Mauchly's test indicated that the assumption of sphericity had been violated for the interaction between social presence and communication role ($\chi^2_2 = 18.71, p < .001$). The degrees of freedom were, therefore, corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = 0.71$). We expected this interaction effect to cause the lower and barely significant main effect for social presence. The presence of one or four others influenced the amount of social attention the participants displayed in opposite directions, depending on the stage of interaction. Specifically, when the participants were sitting

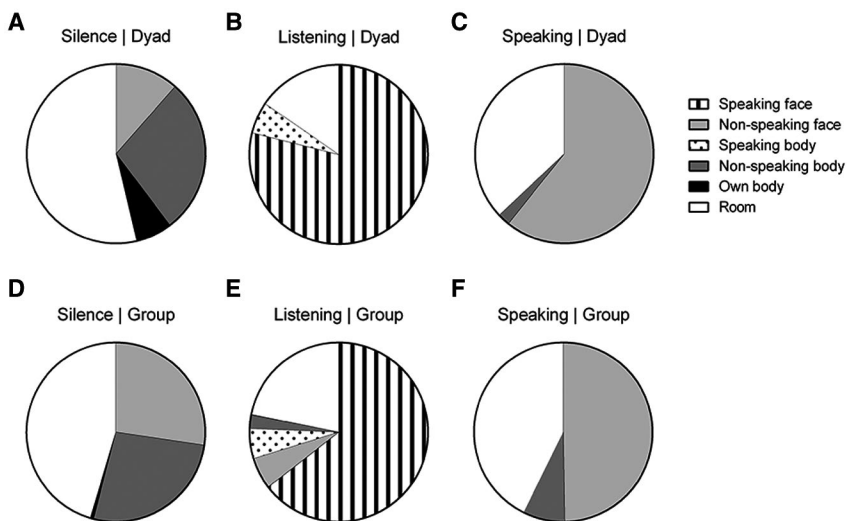


FIGURE 4. Proportions of gazes towards different regions of interest during different stages of the experiment. Entire number of gazes expressed as proportions of gaze locations during sitting silently in a dyad (A), being actively engaged in a dyadic conversation while listening (B) and speaking (C), sitting silently in a group (D), being actively engaged in a group conversation while listening (E) and speaking (F).

in silence with one person, we measured less visual attention compared to when they were sitting in silence in a group of five. However, when they were engaged in a conversation by listening or speaking, they showed more attention to others in the dyad than in the group.

Since in the group interaction there were multiple others to gaze at, we further analyzed which confederate captured the participants' visual attention while they were listening. We found the speaking confederate to be looked at more often (69.6%, $SE = 2.3\%$) than the listening confederates (7.8%, $SE = 0.8\%$; $t_{36} = 23.99$, Bonferroni-adjusted $p < .001$, $d = 3.94$, $BF_{10} = 3.39e+20$; with all participants following this trend).

In summary, these results confirm our third hypothesis, and offer a more differentiated picture than the mere notion that social gazing is more pronounced in a dyadic interaction compared to a group, by revealing that these differences in gaze behavior are reversed when the participants remain silent.

Looking further into the patterns of social attention, the results for gazes towards faces largely resembled our findings for changes in the participants' rate of social gazes overall, that is, including faces and bodies (see Supplementary Information for additional analyses on the number of gazes towards faces).

DISCUSSION

The human eye is more than just a prime instrument for gathering information which composes the human experience. In fact, it has uniquely developed to facilitate nonverbal signaling, which is fundamental to human social exchanges, adapting to meet the requirements and affordances of a myriad of social situations, from intimate private exchanges to public workplace interactions. In this vein, laboratory results employing static visual social stimuli are prone to missing out half of the human eye's functionality: its signaling function (Grossman, 2017). Therefore, our understanding is shallow of how gaze behavior operates during the flow of a real social encounter (e.g., Risko et al., 2016). This study provides first insights into the attentional anatomy of everyday interaction, while maintaining a degree of control that permits a thorough quantitative analysis. Our findings reveal that subjects who were engaged in active conversation, either speaking or listening, looked more at others compared to when they were sitting in silence (Hypothesis 1), and that subjects tended to display more social gaze behavior when they were listening to others than if they were speaking themselves (Hypothesis 2). Furthermore, upon increasing the group size from a dyad to a group of four conversational partners, gaze patterns diverged in two specific ways. First, less visual social attention was shown to others in a group both while speaking and listening, and, second, subjects also showed less overt avoidance of social gazing when sitting in silence in a group compared to the dyad (Hypothesis 3). Our findings hereby shed light on the nonverbal currents shaping exchanges, illuminating a picture of how social gazing differentially manifests itself in dyadic and group conversations.

While engaged in an active conversation, subjects in both dyadic and group settings showed more social gazing compared to when sitting in silence, which lends support for our first hypothesis. The dual function of social gazing as a mechanism to signal information to others, on the one hand, and to gather information about one's environment, on the other hand, may help to explain why eye contact is instrumental for conversation. There exists a common tendency to seek mutual gaze as a crucial signal in the initiation of a conversation (Cary, 1978; Holler et al., 2014). For example, consider yourself standing in a crowd when you recognize someone you know and you want to speak to them. Calling their name may be inappropriate, and so a natural and automatic reaction is to focus on them visually to seek to establish eye contact, and to thus signal to them one's recognition and attention. This is one example of how increased social gazing towards the partner in any face-to-face interaction acts as a potent signal, displaying that one's intentions are directed towards them, and creating a mutual and exclusive connection (Kleinke, 1986; Thayer & Schiff, 1974). In fact, research has shown

that being gazed at acts similarly to hearing one's own name (Kampe et al., 2003). Accordingly, an increase in mutual eye signaling stimulates social cognition, making social gaze behavior a tool that can be utilized to place interacting parties in a mode where they are better able to engage socially (Senju & Johnson, 2009). This pointing function is reflected by the role of gaze in regulating speaking turns in conversations (Ho et al., 2015), an ability that has even been observed in infants who interact with each other by engaging in small turn-taking sequences (Tomasello, Carpenter, Call, Behne, & Moll, 2005). Thus, individuals from a young age direct their gaze towards others to signal their willingness to engage with them. Therefore, it can be summarized that engaging in conversations requires eye signaling, which is reflected by our current data. Participants might, in part, show such heightened eye signaling to meet the various affordances of the social situation, the conversation, in which they find themselves, in order to ensure the success of the interaction. On the other hand, apart from this signaling function, gaze can be utilized to gather information about others during social interactions. Apart from the spoken words, conversations bear a wide variety of nonverbal cues that have to be observed, decoded, and integrated. For example, by watching someone's lips and gathering other cues of nonverbal behavior, we can get a sense of how our counterpart responds to the nonverbal and verbal content we provide to them (e.g., Holler et al., 2014; Summerfield, 1979). Vice versa, nonverbal cues in conversation provide meaning and allow certain points within the spoken content to be additionally emphasized (Holler et al., 2014; Schober & Clark, 1989). This is crucial, because it benefits the dynamic, adaptive flow of reciprocal communication, that is, by being able to respond aptly to our counterpart. To summarize, we argue that our findings of increased social gazing during conversations when compared to silence might be due to an increased need to signal engagement in order to support the connection between the interacting parties, and due to a need to gather the social information which goes beyond verbal content (Ho et al., 2015; Risko et al., 2016; Rosenblum, 2008; Summerfield, 1979).

Further, we find that subjects engaged in more social gazing behavior when they were listening as opposed to when they were speaking, lending support to our second hypothesis. These findings are in line with previous studies which used a multitude of different methodological approaches (e.g., Argyle & Cook, 1976; Dovidio, Ellyson, Keating, Heltman, & Brown, 1988; Freeth & Bugembe, 2018; Freeth et al., 2013). The twofold function of social gaze behavior as, first, a way to communicate engagement in the interaction and, second, to gather information by directing one's attention towards the other may explain the results. First, when involved in a conversation, the mere act of speaking signals engagement with the other, while listening requires the silent individual to use other ways to demonstrate their commitment to the

conversation. When one is allowing another individual to speak, gaze is the most salient channel available to the listener in order to signal one's continued engagement with the other (e.g., Kampe et al., 2003). It is worth taking a look at our primate cousins, in which the power of gaze to act as a form of "touchless grooming" has been shown (Kobayashi & Kohshima, 1997). In a similar way, the non-verbalizing party in a conversational exchange may be put upon to offer something to keep alive the bubble of reciprocal attention. Here, eye gaze either substitutes or crucially supplements other nonverbal signals of engagement, such as approving nods, reactive facial expressions or changes in posture or gesture in response to the content of the conversation. Second, there might be a cognitive predisposition to direct one's attention towards a speaking individual to enhance listening comprehension. More specifically, carefully attending to one's counterpart while listening could support the cognitive processes of comprehension, given that findings show visual attention directed towards a speaker to support the understanding of spoken language (Barenholtz et al., 2016). Interestingly, it has also been shown that visually unaddressed recipients process speech less effectively than those directly addressed (Holler et al., 2014; Schober & Clark, 1989). On the other hand, our finding that speaking led to fewer social gazes may be explained by the distracting effects of directed eye gaze, which arises because gaze from others has the potential to cause cognitive interference (Conty, Gimmig, Belletier, George, & Huguet, 2010; Doherty-Sneddon & Phelps, 2005). Thus, it would make sense to avoid social gazing in order to not disrupt verb generation during speech (Kajimura & Nomura, 2016), a tendency which can be observed even in infants (Doherty-Sneddon & Phelps, 2005). In conclusion, we argue that increased social gaze behavior while listening may serve to sustain the communication channel and enhance comprehension of the listener, while reduced gazing during periods of speaking might be a mechanism to increase fluency of thought in speakers by avoiding the interference caused by social presence of others.

Lastly, individuals who engaged in a dyadic conversation showed more social gazing than those who took part in interactions in groups of five. Therefore, patterns of gaze behavior are modulated by group size, supporting our third hypothesis. In greater detail, we found that conversing individuals show more social attention in dyadic settings compared to group settings. In essence, when engaged in conversation, less visual social attention was shown to others in a group of five as compared to a dyad. However, subjects were also less prone to avoid social gazing when sitting in silence in a group as compared to a dyad. These findings are intriguing because, while the group setting actually offers a broader array of social information, it led to an increase in social gazing only when sitting in silence, not while conversing. Thus, the idea of trying to interpret gaze patterns purely from the

perspective of information gathering is once again revealed as deeply flawed, and the importance of social norms for gaze behavior once again comes to the fore (Risko et al., 2016). But why do these differences between dyad and group arise at all? Our results show a tendency for members of a dyad to avoid looking at each other when not talking, compared to a group. One reason may come from the affordances of the social situation, and the tendency to use gaze to initiate a conversation. Consider two strangers in a train compartment, who may avoid eye contact if they are unwilling to initiate an exchange. In our scenario, participants had been explicitly instructed not to talk. Therefore, it is possible that participants were eager to look at the other person, but suppressed this urge since looking too much at a social counterpart can signal the intention to socially engage in further conversation (e.g., Ho et al., 2015), which was not allowed during that stage of the experiment. This pressure to avoid social gazing as an initiation signal to engage in conversation might be even higher when sitting in a dyad, as compared to sitting in a group with four others, since, in the latter condition, social attention might freely switch between the four counterparts, without focusing too often or for too long on one person.

In sharp contrast, however, heightened visual attention was drawn towards the counterpart during conversation in a dyad compared to a group. We argue that this reflects an effort to create an intimate bubble of mutually exclusive attention, which is characterized by eye contact. Dyadic settings are more common in daily life than interacting in a group (Dunbar et al., 1995), and it is likely that a dyadic conversation represents an environment more conducive to the formation of a mutual connection (Kleinke, 1986). Indeed, evidence shows that social gaze is related to the level of affiliation among individuals, and that it can be used as a nonverbal way of bonding, contributing to a sense of relatedness (e.g., Thayer & Schiff, 1974). Whereas in a group, the need to overtly display participation and engagement in a conversation is distributed among a number of people, in a dyad the onus of responsibility for showing adequate gaze signals lies solely on either subject. Thus, increased social gazing in dyadic interaction reflects a normative engagement in mutual signaling, whereas, vice versa, decreased social gazing in a group might in part be the result of a type of social loafing. In short, when listening to a speaker in a dyad, one is generally under more pressure to show engagement than in a group. Finally, concerning the fact that speakers in a group showed decreased social gaze behavior as opposed to a dyad, the explanation may be found with cognitive interference, as noted above (e.g., Kajimura & Nomura, 2016). Very simply, this interference may increase in a group, due to multiple pairs of eyes and higher amounts of social information, compared to when talking only to one counterpart. To summarize, we found that group size impacts gaze behavior. A dyadic conversation begets an intensified need to sustain a bubble of

intimacy, hence resulting in more gazing. This finding highlights the importance of understanding gaze behavior as a social signal (e.g., Foulsham et al., 2011; Risko et al., 2016), and supports our third hypothesis, with the caveat that the opposite was true of social gazing in periods of silence.

Limitations, Practical Implications and Future Research

Although our findings are consistent across the vast majority of subjects, they do face several limitations. Since our aim was to ensure a naturalistic social interaction while maintaining sufficient experimental control, some restraints in the natural flow of conversation were inevitable (Foulsham et al., 2011). First, and most importantly, participants were instructed when to speak and when not to speak, taking turns to allow for an even distribution of speaking time for each participant. While predefining conversational turns was necessary in the vein of ensuring both control and equivalence between participants, this led our confederates to speak longer than participants during a dyadic situation. This resulted in participants having to wait longer for their turn to speak than during a group setting. This could render our findings more susceptible to bias, simply due to the standardized sequence of events. For example, the mere fact that participants sat together in silence without socializing first, and that they were then—within the conversation—not allowed to speak first or whenever they wanted, could have impacted the way participants looked at their social counterparts. In other words, had the participants been allowed to interact before the silence phase, this might have led to more social attention during the silence phase, as a connection would already have been established (Kleinke, 1986). Hence, the findings might reflect a given gaze pattern for this special situation, which limits its external validity to a certain degree. Second, although confederates were trained well to ensure as natural as possible a mode of engagement with the participants, both in terms of verbal and nonverbal behaviors, and although none of the participants reported having noticed that the others were confederates, here, too, the rehearsed behavior of the confederates could have impacted the gaze behavior of participants. This could be avoided by a more unrestrained and natural type conversation. For example, too much laughter when a participant makes a joke might make the conversation somewhat unnatural. Third, despite high inter-rater reliability, there is a certain degree of imprecision in coding, engendered by the subjective variance in the interpretation of gaze events. Therefore, although the use of mobile eye-tracking technology ensured a high degree of external validity, this goes hand in hand with an inherent cost of decreased internal validity. Lastly, in this study, we focused on eye gaze as one of many nonverbal behaviors. Other behaviors, such as facial

expressions, gestures, or voice tonality may be of equal importance to guide observers' impressions.

There are also noteworthy differences in nonverbal behavior between cultures, and our findings likely represent Western ways of behaving in social encounters (Akechi et al., 2013; McCarthy, Lee, Itakura, & Muir, 2006). Therefore, elucidating cultural differences would be a promising avenue, as it opens up a possible path for understanding and shaping our gaze behavior in intercultural negotiations (Bandura, 2002). Further, a large proportion of our sample consisted of female subjects. Social gaze behavior has been shown to differ with gender (Swaab & Swaab, 2009) and future research is needed to investigate this relationship in greater detail.

The normative ratios of social gaze indicated by our results open up new areas for applied research. Gaze behavior in conversations has been shown to be influenced by social status and expertise (Argyle & Cook, 1976; Dovidio et al., 1988). Deviations from these normative gaze rules might offer information about one's leadership ability and knowledge in the domain at hand (e.g., Maran, Moder, Furtner, Ravet-Brown, & Liegl, 2020). Consequently, assessing and analyzing gaze behavior while conversing within specific settings could provide additional information about individual capabilities and competencies, such as in recruitment interviews. For example, leaders might employ specific patterns of gaze to earn desirable leader ascriptions (Maran, Furtner, Liegl, et al., 2019).

CONCLUSION

Conversation is a pillar of collaboration, and gaze behavior is the mortar which binds conversation together (see, e.g., Grossmann, 2017). By employing cutting-edge mobile eye-tracking technology, we offer a first qualitative and quantitative insight into the normative dynamics of gaze signaling during naturalistic conversation, examining both a dyad and a group interaction. Our main findings include the results that people generally show more social attention when listening compared to when they are speaking, that they generally affect more visual attention when engaged in conversation than when sitting together in silence, and that group size has a profound effect on patterns of gaze behavior. Dyads facilitate social attention during conversation to a greater degree than a group setting, with silence equally diminishing overt displays of visual social attention more in dyads than groups. In summary, we shine a light onto the differential dynamics of gaze, a topic of interest to scientists in both cognitive and applied psychology. In doing so, we provide a stepping stone for others to build on, towards the ultimate aspiration of finally elucidating the function of social gazing outside the laboratory, in the real world.

ETHICS

The study was conducted in line with the guidelines of the Ethics Committee of the University of Innsbruck and participants provided informed consent.

AUTHOR CONTRIBUTIONS

T.M. designed research; T.M., M.F., S.L., L.H., and P.S. performed research; T.M., S.L., T.B., and L.H. coded the eye-tracking recordings; T.M., M.F., S.L., T.B., L.H., and P.S. analyzed data; T.M., M.F., S.L., T.B., L.H., and P.S. wrote the paper. All authors gave final approval for publication.

COMPETING INTERESTS

We declare we have no competing interests.

DATA AVAILABILITY STATEMENT

The materials and data for all studies are available at the Open Science Framework website, osf.io/zcsb7.

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