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Mutual Gaze, Personality, and Familiarity: Dual Eye-Tracking During Conversation

Frank Broz¹, Hagen Lehmann¹, Chrystopher L. Nehaniv¹, and Kerstin Dautenhahn¹

Abstract—Mutual gaze is an important aspect of face-to-face communication that arises from the interaction of the gaze behavior of two individuals. In this dual eye-tracking study, gaze data was collected from human conversational pairs with the goal of gaining insight into what characteristics of the conversation partners influence this behavior. We investigate the link between personality, familiarity and mutual gaze. The results found indicate that mutual gaze behavior depends on the characteristics of both partners rather than on either individual considered in isolation. We discuss the implications of these findings for the design of socially appropriate gaze controllers for robots that interact with people.

I. INTRODUCTION

Gaze is an important component of social interaction. Compared to other primate species humans have very visible eyes [1], [2]. A possible explanation for this phenomenon is the evolution of a new function of the human eye in close range social interactions as an additional source of information about the intention of the other [3]. In many studies it has been shown that apes and monkeys have no or only very limited abilities to follow a human experimenter's eye movement to locate a hidden reward [4]. Human infants on the other hand are able to follow eye movements from around 18 months of age [5].

Humans rely heavily on gaze information from their conspecifics, especially during cooperative, mutualistic social interactions. The importance of eye gaze shows in the trouble humans with autism have in understanding the intentions of others which could be inferred from information contained in the eye region of the face [6], [7], [8]. Gazing and the ability to follow the eye gaze of others enables us to communicate non-verbally and improves our capacity to live in large social groups. It serves as a basic form of information transmission between individuals which understand each other as intentional agents. Additionally, human eyes signal relevant emotional states [7], [9] enabling us to interact empathically. For these reasons, humans need eye gaze information in order to feel comfortable and to function adequately while interacting with others.

Mutual gaze is an ongoing process between two interactors jointly regulating their eye contact, rather than the result of an individual's action [10]. This behavior is of social importance from an early developmental stage; it seems to

be the basis of and precursor to more complex task-oriented gaze behaviors such as visual joint attention [11]. Recent research in neuroscience suggest that episodes of mutual gaze may “prime” the brain for joint attention [12]. Mutual gaze is also important for face-to-face communication. It is a component of turn-taking “proto-conversations” between infants and caretakers that set the stage for language learning [13] and is known to play a role in regulating conversational turn-taking in adults [14].

In order to develop artificial systems with which humans feel comfortable interacting, it is necessary to understand the mechanisms of human gaze. This is especially true in cases where the system that a person interacts with has a humanoid form that includes eyes, as is the case with many interactive virtual agents or robots. Having the capability of producing readable gaze behavior may lead humans to expect these agents to exhibit natural and/or meaningful gaze, and the quality of interaction may be reduced if these expectations are not met.

There have recently been a number of studies on people's responses to mutual gaze with robots in conversational interaction tasks. But the models used to produce the robot's gaze behavior are typically either not based on human gaze behavior or not reactive to the human partner's gaze actions. In work by Yoshikawa and colleagues, the robot responds to human gaze, but its gaze controller is not based on human data and does not take any action to regulate the duration or frequency of mutual gaze [15]. In a story-telling robot study by Mutlu, Forlizzi and Hodgins, a robot produces human-directed gaze behavior based on a model with realistic timings that is not responsive to its audience's gaze [16]. Yu and colleagues performed a temporal analysis of human gaze and speech behavior from a human-robot interaction word teaching task with a robot that autonomously performed a simple form of joint attention [17]. While this study provides insight into patterns of human gaze at a robot, the simplicity of the robot's controller makes it unlikely that humans found the gaze interaction to be natural or its dynamics to be similar to gaze between two humans.

We hypothesize that correctly modelling the social aspect of gaze is important to achieving natural interactions between humans and agents that give gaze cues, and there is some experimental evidence to support this. In a study of interaction with a virtual agent, simple approaches to achieve high levels of mutual gaze through constant attentiveness by the agent led to negative reactions from the people the agent interacted with, demonstrating the need for a more realistic model [18]. In a study comparing human tutoring

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behavior towards a human child and a childlike virtual robot, Vollmer and colleagues used a gaze controller based on low-level salience rather than the face-oriented nature of human social gaze [19]. In their discussion of their results, they suggest that the robot’s gaze policy may have affected tutoring behavior, causing people to interact differently with the robot because its gaze was noticeably dissimilar to a child’s. Gaze behavior is part of conversational interaction, and the robot’s gaze policy will have an impact on both the human’s gaze behavior and the impressions they form about the the agent they are interacting with. Robotic systems designed to learn language through interaction by exploiting the structure of child-directed speech (e.g., work by Saunders et. al. [20]) could especially benefit from a gaze model that supports social engagement.

In order to support natural and effective gaze interaction, it is worthwhile to first look at gaze behavior in human-human pairs. By examining human gaze, we can gain insight into how to build better gaze policies for agents that interact with people. There has been some previous research into using automated collection of human-human gaze data to produce agent gaze. Raidt and colleagues conducted a study into face-to-face real time communication and gaze direction [21]. However, people interacted through a pair of video displays, which, while appropriate to their computer-agent model, unnaturally constrains people’s options for movement (as opposed to co-located face-to-face conversation). Also, the speech task involved was one of repetition and memorization rather than natural conversation. Given these constraints, it is unclear whether the data collected is representative of human conversational gaze behavior.

Existing research into human behavior tells us that more mutual gaze is positive for engagement [22], while too much can be threatening or stressful [23]. But there has been less research on what characteristics of individuals or pairs of people might lead to differing amounts of mutual gaze during naturalistic conversational interactions. There is evidence of correlations between the amount of mutual gaze engaged in by individuals and their personality dimensions [24]. Familiarity has also been found to be associated with higher levels of mutual gaze [25]. Understanding how individuals’ gaze behavior interacts to produce differing amounts of mutual gaze and what factors might influence the amount of mutual gaze that a person finds comfortable are important issues for creating socially appropriate gaze controller for interactive agents. Learning about these factors by studying human interaction gives suggestions for how to design controllers that can adapt to individual differences in order to exhibit engaging and comfortable amounts of mutual gaze across many different interactions.

II. SYSTEM OVERVIEW

The automated detection of mutual gaze requires both face tracking and gaze tracking to be carried out and their separate data output streams to be combined for further processing. For these experiments, two ASL MobileEye gaze tracking systems were used to collect the gaze direction

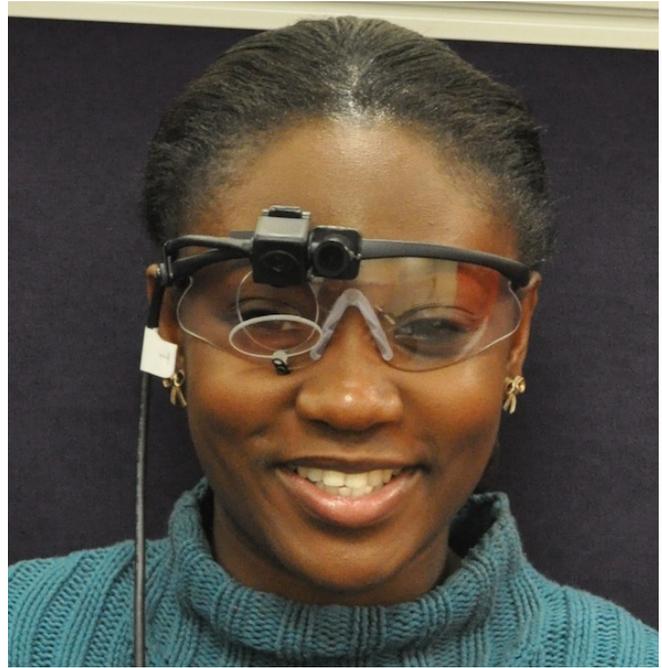


Fig. 1. Experiment participant wearing the ASL eyetracking system. The scene camera is mounted on the glasses, pointed in the direction that the wearer’s head is facing.

data [26]. Each experiment participant wore one of these glasses-mounted systems (Figure1). The system measures gaze direction within the field of vision of a scene camera mounted on the glasses, pointed straight ahead at what the wearer is facing. The system software logs gaze direction in image pixel coordinates, along with the video input from the scene and eye-directed cameras used by the tracking system. The gaze coordinates are indexed by their corresponding video frame.

After data collection using the gaze tracking system, video from the scene camera was used as input to face-tracking software based on the faceAPI library [27]. Recording the video and then running the face-tracking software offline allowed for improved tracking performance because the algorithm was not limited by the computational constraints of needing to run in real-time. The face-tracking software outputs a face bounding box and facial feature coordinates, indexed by the video frame number. The coordinates are expressed in image pixels, which can be directly compared to the gaze coordinates recorded by the gaze tracking system because the same scene camera video file is used by both systems for each subject from whom data is collected.

III. EXPERIMENT

For the experiment, 37 pairs of participants were recruited from the university campus. The only requirement for participation was that a participant be comfortable having a fifteen minute conversation in English with their experiment partner. The participants were informed that their gaze and speech data would be recorded during the experiment. The participants were instructed that they were allowed to discuss



Fig. 2. Experimental setup for the conversation pairs.



Fig. 3. A timestep of interaction showing the face tracking and gaze direction data for a conversation pair for both of the participants' corresponding video frames. This corresponds to a high level behavioral state used for analysis (in this example, the Mutual Gaze state).

any topics they liked during their conversation. In case they could not think of a topic, a list of “ice breakers” was provided. These suggested conversation topics included: hobbies, a recent vacation, restaurants, television shows, or movies.

The pairs were seated approximately 1 meter apart with a desk between them (Figure 2). At the beginning of the session, the participants were administered a paper survey to collect their demographic information and level of familiarity with their partner. Each participant was guided through the calibration procedure of the gaze tracking system by the experimenter. Two directional microphones were used to record the speech data of each participant (speech data was not used in the analysis for this paper). At the beginning and end of the conversation, the experimenter clapped his hands over the table visible to the scene video cameras of both gaze trackers. During data collection the experimenter stayed behind a divider out of sight of the participants in order to minimize possible distraction or bias created by his presence. At the end of the session, participants were asked to complete a short paper questionnaire, the Ten Item Personality Inventory (TIPI) [28], in order to evaluate their personality dimensions.

IV. DATA COLLECTION AND PROCESSING

The gaze data for a participant and the face tracking data for their conversation partner can be easily associated for each frame of scene camera video of the experiment

conversation. This produces an individual data file of aligned gaze and face data (containing their gaze direction and the location of their partner’s face in the video frame), indexed by frame number. This data allows an individual’s face-directed gaze at their partner to be measured frame by frame at the 30 Hz frame rate of the gaze tracking system.

Because we are interested in mutual gaze, the data for both individuals in a conversational pair must be combined so it can be determined where each was looking at a given point in the interaction. It is critical to correctly align the face and gaze data for each participant with their partner’s so that that data from the video frames recorded closest together in time are combined for analysis. This alignment was achieved by manually locating the frames in which handclaps occurred at the start and end of conversation in each partner’s scene camera video files. Two aligned frames from a conversation with their gaze and face tracking data overlaid are shown in Figure 3.

A. Behavioral States

At each time step, the face and gaze data for the video frame of each partner was analyzed to determine whether their gaze location fell within the bounding box for their partner’s face. Then the combined detection of face-directed gaze for both partners is used to classify the behavioral state of the gaze interaction for that time step.

The behavioral states and their descriptions are given in Table I. Note that the states are mutually exclusive. In all pairs observed, one participant looked at their partner noticeably more than the other. The participant that performed the higher amount of face-directed gaze is referred to as the “High” gaze participant and the partner that was gazed at more than they gazed is referred to as the “Low” gaze participant.

For each pair, the percentage of time steps classified as belonging to each state over the time period of analysis is calculated and used for analysis. Certain time steps were not classifiable due to missing readings from the face or gaze tracker for either partner. These time steps were excluded from analysis.

B. Other Measures

Information was also collected about the participants using the paper survey and questionnaire described in Section III. The TIPI test was used to evaluate participants according to the five personality dimensions defined by Costa and McCrae [29]. These dimensions are:

- Extraversion
- Agreeableness
- Openness to new experience
- Emotional stability
- Conscientiousness

This test produced a score from 1 to 5 for each dimension for each participant. In addition to the personality dimensions measured, each participant recorded how familiar they felt they were with their partner on a 5-point Likert scale ranging from 1 = “not at all” to 5 = “close friends”.

Behavioral State	Definition
<i>Individual Gaze Behavior</i>	
Gazing At	Gaze at partner’s face, regardless of where partner is looking
<i>Pair Gaze Behavior</i>	
Mutual Gaze	Both participants looking at one another’s face area
At Low	The high gaze level partner looks at the face of the low gaze level partner while they look elsewhere
At High	The low gaze level partner looks at the face of the high gaze level partner while they look elsewhere
Away	Both partners look somewhere other than their partner’s face

TABLE I
DEFINITIONS OF BEHAVIORAL STATES

Because the behavioral state of mutual gaze describes pair gaze behavior, we needed a corresponding way of looking at the individual scores produced by the paper surveys in terms of the traits of the pair. In order to do so, we combined the scores in such a way as to measure the similarity and difference of each pair member in regards to each measure. To transform the individual personality and familiarity scores into scores for a pairing, the sum and the difference of the score for the members of a pair were calculated.

There are factors other than personality or familiarity that have been shown to influence gaze behavior, but their investigation is outside the scope of this particular study. The relatively large number of 74 randomly selected participants from different social and cultural backgrounds enabled us to have a good cross section of potential differences in gaze behaviour based on these factors and their interactions with social roles, gender and personality traits.

V. RESULTS

For the analysis, the data from 34 of the 37 pairs were used. Two pairs had to be excluded due to technical difficulties in the calibration process leading to the early termination of the experiment. One pair was excluded from analysis because of poor performance by the face tracking software due to large amounts of rapid head moment during conversation. For each pair, the 12 minutes of contiguous data with the smallest number of missing readings was selected for analysis. This criteria was chosen to maximize the amount of useable data for comparison and to automatically eliminate periods at the beginning or end of sessions when the participants might be attending to the experimenter rather than one another. Because the experimenter clapped each session in and out while standing to the side of the table, readings for a partner’s face were likely to be lost when looking at the experimenter, either because their face was outside of the scene image or because it was rotated to be in profile as they looked at the experimenter. The data was classified into high-level behavioral states depending on participants’ face-directed gaze.

We analysed the data to investigate links between gaze behavior states and other traits using Pearson’s product-

moment correlation coefficient. We looked for correlations both in individual and in pair behavior.

A. Individual Gaze

We looked for correlations between individual gaze behavior related to mutual gaze (the Gazing At state defined in Table I) and the personality dimensions of the individual as measured by their TIPI scores and their reported level of familiarity with their partner. There were no statistically significant correlations found between any of these traits and the amount of time an individual spent gazing at their partner. There was, however, a strong trend found between Gazing At and the agreeableness score (Table II). It would seem that the amount of face-directed gaze in an interaction does not depend strongly on an individual’s characteristics considered in isolation. As we will see in the next section, gaze behavior arises from the interaction of the personalities and level of familiarity of both members of a pair.

B. Gaze Between Pairs

A number of different gaze states occur between pairs that rely on their combined behavior: mutual gaze, nonmutual face-directed gaze, and simultaneous gaze away from one another. We were interested in investigating how the amount of time spent in these gaze states might relate to the interactions of the personality and familiarity of the pair considered as a unit rather than individually. We looked for correlations between the pair behavior gaze states and the combined scores for personality and familiarity. The statistically significant correlations found are shown in Table III.

On average, the percentage of the interaction spent in mutual gaze (the Mutual state) was 45.7% ($s = 18.5\%$) and the percentage that both of the participants spent looking away from one another (the Away state) was 10.2% ($s = 9.7\%$). Timesteps were only classified into a gaze state if face and gaze tracking coordinates were available for both participants and timesteps without a gaze classification were excluded from the analysis. A participant looking away was more likely to result in missing data, either because their partner’s face was not within the camera frame or because gaze far to the periphery caused the gaze tracker to temporarily lose

States	correlation coefficient	significance level
Gazing At and Agreeableness	$r = 0.237$	$\alpha = 0.055$

TABLE II
CORRELATIONS (PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENT) FOR INDIVIDUALS.

States	correlation coefficient	significance level
<i>Gaze and Personality</i>		
Mutual Gaze and Sum of Agreeableness	$r = 0.361$	$\alpha = 0.036$
Away and Sum of Agreeableness	$r = -0.347$	$\alpha = 0.045$
<i>Gaze and Familiarity</i>		
Mutual Gaze and Sum of Familiarity	$r = 0.339$	$\alpha = 0.05$
<i>Gaze and Individual Behavior</i>		
Mutual Gaze and At Low	$r = -0.74$	$\alpha < 0.001$
Away and At Low	$r = 0.346$	$\alpha = 0.045$

TABLE III
CORRELATIONS (PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENT) FOR PAIRS.

their pupil. Analysis of the dynamics of gaze state changes performed on data from a pilot study provides evidence that timesteps with missing data were most frequently preceded by the Away state [30].

Recall that a strong trend between gazing at a partner and agreeableness was seen at an individual level. In the pairs' behavior, there is a strong correlation between the sum of a pair's agreeableness scores and the percentage of time that they spent in mutual gaze. This result shows a personality similarity that is associated with high amounts of mutual gaze. There was also a negative correlation found between the Away gaze state and the sum of the agreeableness, which shows that pairs with high agreeableness also spent more time looking at each other overall, even when the gaze was not mutual. These were the only sums or differences of a personality dimension score for which gaze state correlations were found. It might seem somewhat surprising that correlations were not found for dimensions such as extraversion or emotional stability (neuroticism), but the lack of existing research on the effect of personality on mutual gaze during natural interaction makes it difficult to know whether these dimensions should actually be expected to have an effect. The strong relationship between agreeableness and mutual gaze suggests that negotiating mutual gaze effectively may be important to the impressions that people form about how agreeable a person or agent is to interact with.

A correlation was also found between mutual gaze and the sum of the familiarity scores of a pair (Table III). This result is interesting in that there was no such correlation found in the individual gaze data. So while familiarity did not relate to how much an individual looked at their partner, their gaze was returned by their partner more often in

association with how well they both knew each other. This result raises some design questions for gaze for robots or virtual agents that warrant further investigation. If an agent is interacting with unfamiliar people, should its gaze controller attempt to maintain less eye contact than when interacting with someone familiar? High amounts of mutual gaze are associated with agreeableness, but it might be that gaze behavior that seeks to establish mutual gaze with a stranger too often could be unnerving.

In order to try to better understand how mutual gaze arises between a pair of interactors and what influence an individual has on the amount of mutual gaze, we looked at the relationship between when both partners were looking at or away from one another and when only one was looking at the other. In all pairs, there was a High and a Low gaze participant, so we classified each member of a pair as such in order to compare nonmutual face-directed gazing across all the pairs. The average percentage of time during an interaction that the high gaze participant looked at the low gaze participant while the low gaze participant looked away (the At Low state) was 30.6% ($s = 13.1\%$). The average percentage of time spent in the At High state, which is the equivalent measure for the Low gaze participant, was 13.4% ($s = 6.2\%$). A strong negative correlation was found between the amount of mutual gaze and the amount of time that the high gaze participant looked at the low gaze participant while they looked away (Mutual Gaze and At Low in Table III). No correlations were found between mutual gaze and unreturned gaze to the high gaze participant or both partners looking away from one another (At High or Away). Our hypothesized explanation for this correlation is that the low gaze participant may control the amount

of mutual gaze during an interaction by not returning the gaze of their partner. Another correlation that relates to this hypothesis is that the percentage of time both partners spent looking away from each other during an interaction was positively correlated with the percentage of time that the high gaze participant looked at the low gaze participant (Away and At Low). When the high gaze participant looked at the low gaze participant more, the pair looked at one another less overall. This behavior may be indicative of a less effective interaction with a reduced opportunity to share information through gaze.

This is a result that may have a great deal of significance for gaze control for interactive agents. While mutual gaze is desirable to help people form positive impressions of an agent, these results suggest that mutual gaze cannot be increased simply by looking at the interaction partner more. People will respond by avoiding gaze in order to prevent a larger amount of eye contact than they are comfortable with. Causing people to feel the need to do this may negatively affect interaction by making a person uncomfortable or causing them to form a poor impression of their partner. It may also deprive both members of the pair of the additional information communicated during interaction through natural gaze behavior.

VI. FUTURE WORK

While the use of automated tracking methods to study mutual gaze is an interesting direction of research in its own right, this work was conducted as part of an effort to create data-driven gaze control for a social robot that engages in conversational interactions with people. Collecting data from human-human interaction provides a dataset that can be used to build or learn such a controller. The analysis of these human-human interactions also provides insight into the factors influencing mutual gaze as well as the performance of automated methods for detecting it.

Because mutual gaze is the product of interaction rather than individual behavior, there are open questions about how a robot or agent should perform it so as to be most acceptable to humans. For example, pairs of people who scored high in agreeability also exhibited high amounts of mutual gaze. So one might reason that a robot should exhibit high levels of face-directed gaze in order to increase mutual gaze and appear agreeable. But the negative correlation found between the Mutual Gaze and At Low states suggest that people who prefer lower levels of mutual gaze may achieve these levels by not reciprocating their partner's face-directed gaze. Our results also suggest that it may be beneficial for a robot to adapt its amount of face-directed gaze based on how familiar a human is with it.

The gaze policy that people prefer in a robot is likely to depend on their individual characteristics, background, and impressions of the robot. The ability to make inferences about these preferences may prove to be important for designing controllers that are appealing and effective in communication with a wide range of users. In many cases, these individual differences cannot be directly observed.

Therefore, we intend to pursue a modelling approach that can capture the statistical relationships between observable and unobservable variables and that supports sequential action selection optimizing desired targets for behavior in the face of uncertainty. Partially observable Markov decision processes (POMDPs) have these characteristics [32]. For one example of how human-human task performance has been used to create a POMDP controller for human-agent social interaction, see prior work by Broz et al. [33].

Recently, the dataset from this experiment has been manually annotated with each participant's conversational role (i.e., speaker or listener) at every time during the interaction. Speaker role has been shown to influence how much a participant in a conversation looks at their partner [31]. Adding this dimension to the dataset will allow us to build an awareness of speaker role into our controller, therefore improving the realism of the robot's gaze during conversational interaction by allowing the robot's conversational role to influence its gaze behavior. The implemented models will be evaluated and compared to other gaze control strategies during interaction between humans and the iCub humanoid robot [34].

VII. CONCLUSIONS

In this paper, a system for the automated detection of mutual gaze was described, and results were presented from natural conversational interactions between human pairs. We found that mutual gaze correlated with the combined agreeableness of a pair of participants as well as their combined familiarity with one another. These correlations between gaze and personality and familiarity occurred in the pairs' gaze behavior and not in the gaze behavior of individuals. These results suggest that mutual gaze behavior during an interaction depends on the characteristics of both participants. Additionally, we observed that the amount of gaze by the high gaze participant in an interaction was correlated with more gaze away from one another and less mutual gaze. Based on these correlations, we hypothesize that high amounts of gaze may cause a partner to avoid returning gaze. Mutual gaze is an outcome of interaction, and gaze controllers that are designed only in terms of producing individual behavior without considering the interaction partner may not lead to natural and effective gaze interaction between humans and interactive agents.

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