Looks Can Be Deceiving: Using Gaze Visualisation to Predict and Mislead Opponents in Strategic Gameplay

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ABSTRACT
In competitive co-located gameplay, players use their opponents' gaze to make predictions about their plans while simultaneously managing their own gaze to avoid giving away their plans. This socially competitive dimension is lacking in most online games, where players are out of sight of each other. We conducted a lab study using a strategic online game; finding that (1) players are better at discerning their opponent's plans when shown a live visualisation of the opponent's gaze, and (2) players who are aware that their gaze is tracked will manipulate their gaze to keep their intentions hidden. We describe the strategies that players employed, to various degrees of success, to deceive their opponent through their gaze behaviour. This gaze-based deception adds an effortful and challenging aspect to the competition. Lastly, we discuss the various implications of our findings and its applicability for future game design.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces: Input devices and strategies

Author Keywords
Deception; Gaze Visualisation; Competitive Gameplay; Intent Recognition; Plan Recognition; Nonverbal Leakage

INTRODUCTION
In face-to-face communication, our eyes have a dual function: to perceive the environment and to signal our point of interest within that environment [20]. In this context, gaze is an important behavioural cue that reveals our unspoken intentions to other people [7]; researchers call this "nonverbal leakage" [15]. As a result, interpreting gaze is a competitive element in many games, where players can gain advance warning of what their opponent intends to do by accurately reading their gaze. Variations on this tactic abound in all types of games, from poker players wearing sunglasses indoors to hide their eyes, to footballers using a "no look pass" to mislead opponents about the direction in which they will move the ball. As these examples show, counter-strategies for gaze interpretation range from the defensive (obscuring gaze) to the delusive (portraying a false intention through gaze).

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By contrast, digital games rarely allow for gaze interpretation, as players are hidden behind screens and sometimes physically remote from each other. In a recent survey of gaze interaction in games, Velloso and Carter found an increasing number of applications in single-player scenarios [41], but limited usage in multiplayer and online games. HCI researchers have begun to explore the uses of shared gaze awareness in multiplayer games, finding that gaze visualisation can increase the feeling of social presence between remote players [27, 33]. However, despite its prevalence in face-to-face games, *gaze-based deception* in online gameplay has not yet been the subject of published research. This paper contributes the first study (to our knowledge) of human-to-human deception through gaze visualisation in an online strategic game.

In this study, we observed pairs of players engaged in an online turn-based strategy game with incomplete information, in the form of hidden objectives. Each player's gaze was tracked and, in some conditions, transmitted to their opponent and displayed as a dynamic heatmap overlaid on the game. The study involved three rounds of the game, corresponding to three study conditions: *no gaze visualisation*, *gaze visualisation of an unaware player*, and *gaze visualisation of an aware player*. First, consistent with the findings of our prior study [34], the findings of this study showed that players made more comprehensive and more precise predictions about their opponent's intentions when they were shown a gaze visualisation of an opponent that was unaware they were being tracked. Second, we find that players who knew their own gaze was being visualised were able to deceive their opponent with gaze, through both obscuring their true intentions and conveying false intentions. Following, we discuss the implications and applicability of these findings for future game design. Lastly, this paper contributes a typology of such gaze deception behaviours, categorised as *dissimulation* and *simulation deception strategies* according to the general theory of deception [4, 5].

LITERATURE REVIEW
Gaze and Intention
Gaze is a powerful form of nonverbal communication, as its direction alone can convey a number of signals, including one's current point of attention and future intentions [26]. Gaze often gives away this private information without our knowledge or intent, as "nonverbal leakage" [15]. It is common therefore for players in face-to-face games to peek at their opponents' eyes to obtain clues as to what they will do next. Psychologists theorise that this inherent human ability to discern others' intentions stems from our *Theory of Mind*—the ability to put

ourselves into another person's position and imagine how they might think and act—and that gaze is an important component to this ability [3, 28].

Gaze observation is a missing component in much technology-mediated human-human interaction. With the emergence of affordable eye trackers, researchers have begun to explore its uses in remote collaborative settings using visual representations of gaze (e.g. [2, 10, 30, 40]), and have shown that it can improve both communication and coordination. Similarly, a small body of work has emerged in recent years that explore eye-tracking technology as an input for digital games. Primarily this has concerned the creation of novel gaze-based gameplay experiences [39, 41], with only a few studies to date looking at shared eye tracking in competitive multiplayer games including our own [27, 34, 35, 40]. Typically, players of online games cannot see their opponents and so do not have access to the kinds of immediate behavioural cues (such as gaze) that enrich the experience of playing games in a physically shared location. In our previous work on the subject, we found that adding a visualisation of an unseen player's gaze into a digital game allowed spectators to make accurate predictions of what the player was planning to do, based on the areas of the screen receiving the most visual attention [34].

However, digital gaze visualisation is not a perfect replacement for face-to-face gaze observation. Researchers have found that live gaze visualisation from an eye tracker can be distracting and difficult for the observer to interpret, especially when there is a mismatch between gaze and other forms of communication [11, 30]. Furthermore, HCI researchers have found that the intended meaning of gaze behaviour can be difficult to discern through a visualisation [23], as it is often "hard to distinguish between deliberate communication and unwanted inputs" [33].

Gaze and Deception

As we use gaze cues to predict the intentions of others, gaze can be used against us as a method of deception. Players in many games mislead their opponents by simulating a fake intention with their gaze, as in a footballer's "no look pass". In *LaserViz*, the researchers simulated this mechanic using a two player shell game variation using cards, with one player wearing a head-mounted laser (that corresponds to the wearer's gaze) acting as the mixer [40]. The wearer initially experienced a disadvantage as the opponent could correctly guess their plans based on the gaze visualisation but in subsequent rounds, the advantage was reversed as the wearer learned to trick their opponent by consciously looking at the wrong card.

The effectiveness of misleading gaze behaviour is predicted by Levine's *Truth-Default Theory* [29], which holds that humans have a strong tendency to presume that another person is communicating honestly, and that lies are usually only detected after-the-fact based on contradictory evidence rather than through observation of the liar's demeanour. Levine explains this as an adaptive tendency for most situations, as lies are much rarer than truths, but one that leaves humans vulnerable to deceit. We believe this theory can be generalised to scenarios in which the communication is solely nonverbal.

Studies have found that humans have a limited ability to differentiate between true and deceptive gaze behaviours (e.g. [16]) despite developing this ability at young age. Freire et al. found that children as young as four years old could detect small "leaked" gaze cues, and use them to infer that a person's private thoughts were contradictory to their verbal statements [17]. Then again, people are also able to adopt honest-seeming gaze behaviour when they lie to avoid suspicion. For example, Mann et al. found that people maintained eye contact when lying to foster trust, by taking advantage of the popular belief that liars avoid eye contact [32]. This suggests that distinguishing between true and deceptive gaze signals is a difficult task that could provide a rich resource for challenging social play.

Gaze and Plan Recognition

The problem of plan recognition has long been investigated by artificial intelligence researchers. Kautz and Allen define plan recognition as "the task of inferring intentions (in terms of plans) from the actions or utterances of observed actors" [25]. Plan recognition is an important aspect in real-time strategy games, as human players who discern the plans of their opponents can gain a significant advantage. Further, players with knowledge of their opponents plans will allow them to employ some form of deceptive behaviour. Cohen et al. outline two types of plan recognition, *keyhole* and *intended* [9]. *Keyhole recognition* is the inference of an agent's goals and plans through unobtrusive observation, as if through a keyhole. The agent has no intent to communicate its goals to the observer. *Intended recognition* is the conveyance of an intentionally constructed impression of an agent's goals to the observer; it is typically found in adversarial settings, such as warfare, in which deceptive strategies are employed to thwart the recognition of the agent's true plans [8].

Strategic games have commonly been used as a context for adversarial plan recognition research (e.g. *StarCraft* [24]). Likewise, they have also been used in automated deception detection studies (e.g. *Mafia* [12]), which is a challenging problem that requires the combination multimodal inputs to effectively detect [1]. Although a large body of literature exists in these research areas, our interest for the purposes of this paper lies in plan recognition by human subjects. We seek to test whether a player who follows a live gaze visualisation will obtain the same benefits as *gaze following*, enabling them to discern their opponent's intentions and plans better.As previously mentioned, players in online games lack access to social cues, limiting their ability to discern plans until sufficient explicit information is provided. Byom and Multu explain that are three mechanisms of *Theory of Mind*: (1) knowledge of shared contexts, (2) perception of social cues, and (3) interpretation of actions, all of which are crucial when attempting to discern future behaviours [6]. The use of an online strategic game with incomplete information combined with the introduction of gaze visualisation allows us to study this effect. Furthermore, such games typically require players to construct hypotheses plans (that we can measure), and at the same time invite treachery, trickery and deception [37]. Additionally, playing strategic games have been found to activate regions of the brain associated with *Theory of Mind* [18]. Our work lies at several crossroads, as we begin to explore the potential of gaze as a playful nonverbal avenue for deception while drawing on its roots in face-to-face human communication.

AIMS

We aim to explore the uses of gaze visualisation in online multiplayer games by understanding its potential usage for intention-reading and deception. Gaze, being a key signal for *Theory of Mind*, can assist a player to accurately imagine the mind of their opponent and thus help them to plant false beliefs. We formed the following hypotheses about this activity, based on our review of the literature:

[H1] Players who have knowledge of their opponent's gaze are better at discerning their opponent's overall plans.

[H2] Players who are aware that their gaze is being watched will alter their gaze behaviour to deceive their opponent.

[H3] When a player knows their gaze is being watched and attempts to mislead their opponent through deceptive gaze behaviour, the opponent will not detect the deception.

[H4] Players will be less accurate at predicting the plans of their opponent when the opponent knows their gaze is being watched than when the opponent does not know their gaze is being watched.

We aim to build upon our previous work [34] in three ways:

(1) By using players instead of spectators, where players will make use of gaze visualisation of their opponent during live gameplay, balancing the tasks of devising their own strategic plans with making inferences about their opponent.

(2) By assessing the ability of players to interpret and respond to opponents' gaze cues over the course of a whole game, with a particular interest in the ability to make long-term predictions during the early game before in-game actions have been taken. Previously, we were only able to obtain short-term predictions from the short clips used.

(3) By introducing a deception aspect where one player is aware that their gaze is being visualised, to create an opportunity for the player to deliberately manipulate their gaze behaviour to potentially mislead their opponents.

STUDY

We selected the computer game *Ticket to Ride* following the success of its use in our prior work [34]. In this game, players compete to build train routes between adjacent cities across a map of North America, and gain points for building a connection between specific pairs of cities that they are assigned on "ticket" cards (goal cities e.g. *Vancouver - Montreal*), which are unknown to the opponent. Players lose points if they fail to complete ticket cards they hold, and can block each other's paths, as only one player can claim each train route. Therefore, players must plan their train networks carefully to minimise the risk that an opponent will block them by claiming important routes first. More detailed information on the rules of *Ticket to Ride* can be found on the game's website[1].

There are several factors that make *Ticket to Ride* a suitable game for this study, in addition to keeping continuity with our previous study [34]. As a turn-based game, it gives players time to observe their opponent without having to focus on their own actions concurrently. It contains hidden information in the form of secret goals. As a map-based game, it encourages players to look at locations that correspond with their plans—and provides opportunities to do so misleadingly. Finally, it has a short gameplay time (around 30 minutes or less for two players), and is sufficiently simple that players are able to learn the rules and develop an understanding of the general strategies within a few minutes. We structured our study to ensure both players were familiar enough with the game to make predictions about their opponent, and that Player A (P_A) would be familiar with the gaze visualisation format by the third round (see Figure 1) to allow them to develop ideas about how to use it against their CU-GA opponent.

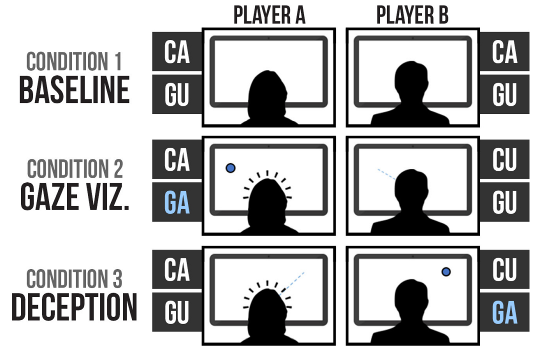

Figure 1: Study Conditions. In C1, no gaze data is visible to either player. In C2, P_A can see P_B's gaze, and P_B is unaware of this. In C3, P_B can see P_A's gaze; P_A is aware of this, and that P_B does not know P_A is aware.

Study Conditions

Each pair of players played three rounds of *Ticket to Ride* against each other, with each player being subjected to a condition (see Figure 1). Each condition consists of the players' awareness of the study condition (**CA**: Condition Aware, **CU**: Condition Unaware) and their awareness of their opponent's gaze (**GA**: Gaze Aware, **GU**: Gaze Unaware). Condition-Aware players were given all details of the study condition for that round, including what their opponent knew. Each players' awareness differed between rounds, as described below. One player was aware of the condition in every round (P_A), while the other was naive after the first round (P_B). The second and third round correspond to *keyhole* and *intended* plan recognition scenarios, respectively [9].

Condition 1 (Baseline)–No Gaze Visualisation of Players

The first round consisted of a standard online match with no gaze visualisation and both players are aware of this, making both players CA-GU (see Figure 1). This round served as a baseline for recording the players' behaviour under normal gameplay conditions. It also allowed players to get experience playing the game to minimise any learning effects, and to get a sense of forming their own strategy while discerning their opponent's strategy, based only on explicit in-game actions.

Condition 2 (Gaze Viz.)–Gaze Visualisation of Unaware Player

In the second round, P_A was shown the gaze of P_B throughout the game, and knew that P_B was not aware their gaze could be seen (see Figure 1). This allowed P_A, as a CA-GA player, to try to discern the intentions of an entirely naive opponent (CU-GU) through their gaze natural gaze behaviour.

Condition 3 (Deception)–Gaze Visualisation of Aware Player

In the third round, P_B received the gaze visualisation of P_A. But this time P_A knew their gaze was being tracked (see Fig-

[1] http://www.daysofwonder.com/tickettoride/en/usa/

ure 1). Not knowing this, P_B (CU-GA) attempted to discern the intentions of P_A (CA-GU) through their gaze behaviour without knowing that they could be intentionally misled.

Recruitment

We recruited 40 players (22 female) from the University of Melbourne, and assigned them into 20 pairs. These included undergraduate students, graduate students and non-faculty staff, aged between 18 and 39 years (M=23.2). Players were compensated with a $20 (AUD) gift card for their time. Before the study, players were asked to learn the rules of the game by watching a video tutorial, if necessary; 11 had played the game previously. A majority self-identified as an "occasional gamer" (23), while the rest self-identified as a "non-gamer" (11) or "regular gamer" (6). Ten players had used eye tracking previously, all as participants in a research setting.

Experimental Setup

The study was conducted in a university usability lab with two players in each session under approval by the University's ethics committee. To simulate online gameplay, we placed players in separate observation rooms and set up an online game of *Ticket to Ride* between them. We provided snacks and bottled water during the study in addition to the compensation due to the duration of each session. Both computers were fitted with a Tobii 4C eye tracker[2], and the gaze data from the eye tracker was streamed between the computers using a custom networked system that overlaid real-time gaze visualisations over any application (also used in our previous study [34]). Players were also given a tablet computer that mirrored their desktop computer screen and instructed to sketch notes about their opponent's strategy on the tablet using a stylus. We placed a video camera in each room to record the players, and the computer screens were also recorded for the duration of each session. Lastly, we logged the raw gaze data of both players for each game round for later analysis.

Procedure

Two researchers were present in each session to facilitate the study and to observe the players. The researchers followed a well-rehearsed script, so as not to reveal the study conditions to the players. On commencement, both players were given an initial briefing together that explained that their gaze would be tracked throughout the study for the sole purposes of later analysis. Players were then randomly allocated into one of the two observation rooms, with one researcher in each. There, players were given a written overview of the study, consent form and basic demographic questionnaire to fill out. Following this, players were calibrated using default calibration procedure of the eye tracking device, and instructed to play the game's interactive tutorial until both players were satisfied that they understood the game for up to 10 minutes.

Players then played three rounds of *Ticket to Ride* against each other through an online connection. To ensure timely completion, each player was given a 15 minute cumulative time allowance for their total turns in each round; if either player ran out of time, we manually calculated the scores for that round. At the start of each round, we requested each player to pick all three randomly assigned 'ticket' cards to complete (each representing a pair of 'goal cities', potentially having up to six initial goal cities). Players were asked to 'think aloud' during the game about their strategy; their opponent's strategy; what they were thinking and what their opponent might be thinking. The researchers prompted the player occasionally on these topics, and took notes throughout the session on player comments or behaviours related to the study objectives. Researchers were permitted to respond to any questions regarding the rules of the game at any time during the session. In the conditions where the player could see gaze, we provided a short tutorial on how we would like them to annotate on the tablet—*circling* the cities they thought were their opponent's goals and *highlighting* the routes they thought their opponent planned to take (see Figure 2). The gaze was visualised as a dynamic real-time heatmap, as our previous study showed that this was the best representation for discerning the goals of a player based solely on a gaze visualisation [34]. The dynamic heatmap visualisation was semi-transparent, and the application allowed the player to click "through" it as normal.

At the end of each round, players completed a brief section of the questionnaire (see *Measures and Analysis* section below for questionnaire details) about the round they just played. At the end of all three rounds, both players were invited to add any final thoughts, and the CU-GA player was asked whether they suspected any deception in the study. Finally, both players were fully debriefed about the study conditions.

Measures and Analysis

Player Self-Assessment and Experience

We created two sets of questionnaires for players to complete following each round of the game, with slightly different questions for each. In both sets, the first three questions following all conditions asked the player to rate their ability to predict their opponent's short-term and long-term plans, and what aspects of the game they had found helpful in predicting their opponent's plans. These repeated measures allowed an assessment of the subjective effects of gaze visualisation and deception on intention recognition ability. We expected that players would make a higher number of predictions when gaze was visualised and that these predictions would be more accurate when the opponent was unaware their gaze was being visualised. To test this effect, we ran a multiple regression model on the questionnaire responses, with independent variables being gaze awareness (whether the opponent's gaze was visualised on their screen or not) and condition awareness (whether the opponent was aware that their gaze was being visualised or not).

For the second and third round, the questionnaire asked additional questions to assess the impacts of gaze visualisation. Both players were asked to rate their experience with the gaze visualisation following the round in which they saw it. After the third round, the CA-GU player was asked whether they attempted to deceive their opponent and how. To test whether the deception of the study had been maintained, the CU player was asked after the second round in what ways the game had been different to the first round; and after the third round, the penultimate question asked whether they felt they had been deceived about the study at any point.

[2] http://tobiigaming.com/eye-tracker-4c/

Prediction Performance

We are primarily interested in players' actual success at discerning the plans of their opponents, as opposed to their self-assessed abilities. To determine this, we first extracted the ground truth (all routes each player claimed) for each individual game for each player (120 games total). We then analysed the study recordings to list all instances in which a player made an inference about their opponent's plan, including both verbal statements and tablet annotations. We then categorised these into *goal predictions* (goal cities the opponent is ultimately connecting to, i.e. their secret objectives) and *subgoal predictions* (what cities or routes they intend to connect through to reach their goal cities). We measured each of these predictions against the opponent's ground truth, defined as the secret objective cities they were assigned by the game, the routes they ultimately claimed, and any routes they verbally declared they were considering but did not end up claiming. We included the latter because players could change their strategy in response to events during the game, particularly after being blocked by an opponent who had correctly guessed their plan. We excluded from the ground truth some incidental routes, primarily any last-minute building decisions in the final turn that were clearly not part of their planning before that point in the game.

We assessed players' prediction performance using three metrics: (1) their accuracy in discerning goals, (2) the extent to which they discerned their opponent's plans, and (3) the *distance* of each guess from the ground truth, in terms of both goals and subgoals. We evaluated players' goal and plan prediction performance by employing the $F_1 - Score$ ($F_1 = 2 \times (precision \times recall)/(precision + recall)$) metric from information retrieval literature [36]. We compared the number of goal cities that were guessed correctly against the total number of cities guessed (*Precision*), and against the number of cities that were in the ground truth (*Recall*). We then performed the same comparisons, replacing the number of correctly-guessed goal cities with the number of goal cities that had been guessed as subgoals. A $F_1 - Score$ value was calculated from both sets of comparisons. Lastly, we employed the *distance* metric from graph theory [42]. As the playing area of *Ticket to Ride* is laid out as a graph diagram, it is possible to determine an error distance by treating all cities as nodes in a graph, and measuring how many nodes the guess was away from the ground truth [31]. To simplify our analysis, we take the shortest distance between the guess to any goal (or subgoal) from the ground truth. Predictions that were adjacent to a goal (or subgoal) thus have a distance of 1, and predictions that correctly matched the ground truth have a distance of 0.

RESULTS

Each session lasted for at least two hours, and consisted of three rounds of *Ticket to Ride* between two players, for a total of 60 rounds or 120 rounds if each player is considered separately. We then compared the extracted predictions made for each player in all conditions against the ground truth for that respective game. The use of the "think-aloud" protocol in our study provided rich descriptions of players' strategies and considerations throughout each of the games. These reflections gave us confidence in our analyses of the game data, as the results are in accordance with what players said themselves.

Effect of Gaze Awareness and Deception

Effect on Player's Self-Perceived Predictive Ability

We examine players' self-perceived predictive ability, i.e. how well they *thought* they discerned the plans of their opponent. We built a multiple regression model to predict player's self-ratings on this measure. A significant regression equation was found for both short-term (R^2=0.23, F(3,116)=11.28, p<0.05) and long-term (R^2=0.20, F(3,116)=9.42, p<0.05) predictive ability. We can define the model based on the latter as follows:

$$Response = 3.27 + (1.8\,(Gaze)) + (-1.32\,(Deception))$$

Both measures are significantly correlated across all conditions for both players (*Pearson(r)=0.78, p<0.05*), meaning that if a player rated their ability to predict specific plans highly, their ability to predict overall goals was also rated highly. The model also shows that there were no learning effects in predictive ability, but there was an increase in players' confidence in their ability to form strategies and make predictions.

Effect on Player's Outcomes and Experience

We first report on players' self-assessments (questionnaire responses), each measured on a 7-point Likert scale (1 being lowest agreement, 7 being highest agreement). Subsequently, we report on the way players spoke about the experience of the game, and the level of success that they achieved.

Overall, players found it easier to make short-term predictions (moves) (P_A=5.6,P_B=5.4) and long-term predictions (strategy) (P_A=5.1,P_B=5.3) in conditions where gaze was visualised. Both sets of players noted the gaze visualisation was useful for formulating their own strategy (P_A=4.9,P_B=5.1), and that it changed the way they played the game (P_A=5.4,P_B=5.2). Both sets of players also believed that gaze visualisation had an influence on the outcome of the game (P_A=5.1,P_B=4.7). In Condition 3, the CA-GU players indicated that they changed the way they played the game as they knew that their opponent could see where they were looking (*M=5.2,SD=1.6)*. Consequently, the players were somewhat bothered by the knowledge that their gaze was being observed (*M=3.9,SD=1.7*), and all of them employed some form of deceptive strategy to counteract this (see *Gaze-Based Deception Strategies* section).

In a comparison of the actual game outcomes in Conditions 2 and 3, we found that the CA players were no more successful than the CU players. This was despite their information advantage, as demonstrated by their greater ability to discern the opponent's true intentions (see Table 1). To explain this, we refer to the comments from the CA player for both conditions. In Condition 2, CA-GA players commented that the gaze visualisation was distracting and drew their attention away from their own plans, both by providing additional information about their opponent's plans and by creating visual clutter on the screen. We believe that this was likely exacerbated by the fact that real-time gaze visualisations were an unfamiliar interface element for all players. The CA-GA players also commented that the visualisation influenced them towards a 'blocking' strategy, which was focused on interfering with their opponent rather than pursuing their own goals. This strategy proved relatively ineffective in many cases, as it caused the aggressor to waste as many turns and resources as the player they were trying to block. For example, $P6_A$ stopped their opponent

				Goal Prediction		Plan Prediction		Distance	
Condition	*Player*	*Won*	*Avg. Predictions*	$F_1 - Score^1$	$F_1 - Score^2$	*Precision (Recall)*	$F_1 - Score$	*Total*	*Mean*
Cond. 1 (Baseline)	P_A (CA-GU)	13	5.8	0.06	0.13	0.49 (0.13)	0.19	25	0.22
	P_B (CA-GU)	7	4.5	0.11	0.19	0.51 (0.11)	0.17	29	0.32
Cond. 2 (Gaze Viz.)	P_A (CA-GA)	11	12.7	0.23	0.44	0.48 (0.34)	0.39	75	0.30
	P_B (CU-GU)	9	5.8	0.02	0.04	0.49 (0.13)	0.18	24	0.21
Cond. 3 (Deception)	P_A (CA-GU)	12	4.0	0.09	0.17	0.48 (0.09)	0.14	24	0.30
	P_B (CU-GA)	8	11.7	0.18	0.35	0.41 (0.28)	0.31	111	0.48

Table 1: Prediction Performance Results. The F_1–*Score*^{2} is calculated based on all cities (goals and subgoals) guessed against the ground truth to find out if players did discern the goal cities did not recognise them as goal cities while F_1–*Score*^{1} is calculated based on only correctly guessed goal cities.

from completing 2 out of 3 ticket cards, but completed none of their own objectives. The CA-GU players spoke about the difficulty of maintaining their deceptive strategies while also thinking about their plans, especially early in the game, noting that it was the best time to be deceptive as their opponent had no other cues. This difficulty in maintaining deception echoes the findings of the *LaserViz* study [40]. Many of the CA-GA players commented that they felt like they were 'cheating' in the second round with an 'unfair advantage', whereas the final round felt more challenging, and generally more exciting. Nevertheless, the CA-GU players found it interesting and engaging to know that their gaze was being watched, and stated that it gave the game added depth.

At the conclusion of each study session, the deceived player was asked whether they suspected that they had been deceived at any point. Only one player expressed some suspicion while the rest did not express any at all. All players expressed the opinion that both they and their opponent had improved their performance each round, which they attributed to ordinary factors such as the luck of the draw or taking greater care in planning their strategies.

Effect on Prediction Performance

Table 1 displays a summary of prediction performance results for all three conditions. A total of 889 predictions (guesses) were made by both players across all conditions. The introduction of gaze increased the average number of raw predictions made compared to when players could not see gaze. Further, we noted that players were able to make their first predictions significantly earlier when given the ability to visualise the gaze of their opponent than in the other conditions without gaze, on average within the first minute from the start of the game. In the conditions without gaze visualisation, the first prediction on the opponent's plans was only made after the opponent claimed a few routes, typically a few minutes into the game. Predictions did become increasingly difficult if an opponent was effective in hiding their intentions. On occasion, the researchers would prompt the player on what they thought their opponent's plans might be, which would often result in a negative response from the player (e.g. *"I don't know", "I am not certain", etc.*), or a brief response with no solid prediction that the researcher could record.

A reason for low prediction counts, particularly in the conditions where players were gaze unaware, is that players often focused on their own plans initially and were less concerned about their opponent's plans until completing their own. This was more likely in round 1 as new players got used to the game. Players may have been particularly good at hiding their plans, in line with the game design, making it hard to make predictions. This led to the predicting players only making predictions when they were confident, leading to a low number of average predictions with high precision but low recall.

In the conditions where players were gaze aware, they explicitly mentioned that they used the gaze visualisation extensively to make predictions, especially in the early stage of the game. This was as expected, as few actions are played in the early stage and the formation of their own plans was still in its infancy. We highlight that players used a variety of in-game actions as well to make predictions, such as observing which colour cards the opponent picked from the deck and matching that to the colour of routes on the board, or observing the general direction in which the opponent was building. Experienced players used the average distance between pairs of cities to gauge whether their opponent had completed a ticket. Other in-game cues contributed to their predictive ability, such as observing which train cards were not selected and analysing opponent's building patterns. Players who frequently annotated on the tablet found it effective for keeping track of their opponent's plans.

In the third condition, the CA-GU players made fewer predictions about their opponent's plans than in the previous rounds. We believe this is for three reasons. Firstly, players focused first on deceiving their opponent and second on attempting to complete their own goals, leaving little attention for discerning their opponent's plans (*"I wasn't focused on predicting their movements but rather on how to throw them off since I know I'm being watched."* [$P9_A$]). Secondly, the deceptive gaze activity required these players to keep track of two sets of plans (true and deceptive), making it hard to keep track of a third. Thirdly, players felt less confident about their predictive abilities after seeing the gaze visualisation and then having it removed (*"I was less able to assess my opponent's strategy than I thought I could. It allowed to see the real advantage of having the eye tracking in the second round. With the eye tracking, I would have been able to see if she was looking at the east coast the entire time."* [$P11_A$]).

Upon calculating the different metrics to determine the effect of gaze and deception on prediction performance, we found that the CA-GA players performed the best overall in Condition 2 amongst the other rounds, despite having the highest number of predictions. There was some degree of error indi-

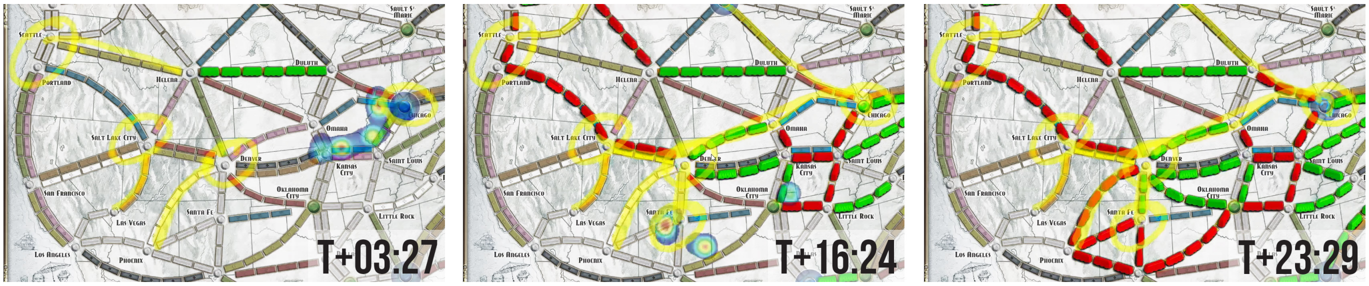

Figure 2: Ticket to Ride Gaze Visualisation Prediction Example. The three figure above shows three stages (early, mid, late) of the same game from left to right, and the real-time heatmap visualisation used in our study. The green tracks belong to the CA-GA player (who has annotations in yellow highlight) while the red belongs to CU-GU player. In early stage, the CA-GA has already predicted part of their opponent's plans, discerning that the opponent is interested in a particular route(s) when no trains have been played yet by the opponent. In the mid stage, we can see how the predicted strategy has been played out and now better discern a different part of their plan. In the late stage, we can see more of the predictions materialising. The figure has been enhanced by reducing the contrast of the background to better show the real-time visualisation, paths claimed and the annotations.

cated by the total distance (75), but this appears to be in the normal range when averaged, meaning that the predictions made did indeed have a distance but was of low value. In contrast, performance scores for the CU-GA players in Condition 3 reveal that they still made more correct predictions based on the goal and plan prediction scores compared to conditions with no gaze. Further, the distance metric did reveal that only 36.6% of the CU-GA players predictions had a distance of over 1 (CA-GA was 26%), showing that the players could still judge their opponents' plans with reasonable accuracy.

We expected the likelihood of players discerning the goals of their opponents to be generally low, especially in conditions without gaze, and this proved to be true ($F_1 - Score^1$). As a further step, we wanted to see if players would guess their opponents' goals as part of a route (i.e. as subgoals) without discerning them as end goals (i.e. without circling them or stating that they were a 'ticket' destination). The results for this analysis were higher ($F_1 - Score^2$), meaning that players did indeed discern goal cities without recognising them as end goals. A further comparison revealed that CU-GU players in Condition 2 had a constant low prediction score, which we believe is attributable to three factors. First, the CA-GA players kept their plans hidden better, by playing a more reserved strategy. Second, the CA-GA players often employed a blocking strategy, causing the CU-GU players to make incorrect or fewer predictions. Third, the CA-GA players completed less of their own intended plans in this round, so there was less on-board information for the CU-GA players to make inferences from. As an additional point, we observed that players commonly extended their routes beyond their goal cities to get bonus points (*Ticket to Ride* gives bonus points to the player with the longest overall route), which made it harder to discern whether the 'ticket' goal was the end of a route or not. In Condition 3, CA-GU players (e.g. $P15_A$) commonly looked beyond their goal cities as a form of *gaze misdirection*.

The CA-GA players in Condition 2 scored an average plan prediction score of 0.39 (*SE=0.031*) when they could see their opponent's gaze, compared to 0.19 (*SE=0.036*) in Condition 1 when they could not. A Welch Two Sample t-test indicated a significant difference between rounds ($t=4.20$, $df=37.23$, $p<0.05$), along with a medium-sized effect $r=0.57$. We thus reject the null hypothesis [H1]. The CU-GA players in Condition 3 scored an average distance error of 0.48 (*SE=0.050*), whereas the CA-GU players in Condition 2 scored an average distance error of 0.3 (*SE=0.033*). A Welch Two Sample t-test indicated a significant difference between rounds ($t=3.01$, $df=413.32$, $p<0.05$), with a small-sized effect $r=0.15$. We thus reject the null hypothesis [H4].

Summary

Our results showed that gaze added value when used to discern plans in a strategic game, especially early in the game, consequently revealing a large part of the tracked player's plans as the game progressed. Figure 2 illustrates how gaze was displayed, followed by its early and partial prediction of an opponent's plan. Further, we found that deception did have an effect on predictive performance, though the player's true intentions still leaked through their gaze. The CA-GU players did need to look at their real plans on occasion and, over time, gave them away as they claimed more routes. As a result, CU-GA players guessed both true and deceptive plans. The results are also consistent with Hypothesis [H3], as the CU-GA players did not state that they were being deceived (as predicted by the *Truth-Default Theory* [29]), when in fact all the CA-GU players did attempt to deceive. Gaze visualisation had overall positive effects on both player experience and player performance, although it was also found to be 'distracting'. The findings also show that the deception condition did cause the CA-GU players to change their gaze behaviour, as they became more aware of where they were looking and sought to deceive their opponent, validating Hypothesis [H2]. The strategies employed are summarised in the section below.

GAZE-BASED DECEPTION STRATEGIES

All CA-GU players in the final round stated that they attempted to deceive their opponent by manipulating their gaze behaviour, and described one or more strategies they used to do so. We categorised the strategies according to the general theory of deception, which divides deception methods into two main categories: *dissimulation* (covert, hiding what is real) and *simulation* (overt, showing the false) [4, 5]. Within these categories, we have created a more specific typology that draws on both the general theory and deception concepts in military strategy, such as camouflaging [13].

Dissimulation Deception Strategies

We observed several ways that players sought to conceal their plans when they knew their gaze was being observed. The most frequently employed and direct dissimulation strategies were *Gaze Averting* (6) and *Information Reduction* (6), followed by *Gaze Scattering* (5). The least employed strategies, *Risk reduction* (3) and *Obstruction* (4) were more oblique, seeking to deny the opponent an accurate target to uncover.

Gaze Averting: Players sought to avoid looking at the routes and cities that were of interest to them. In Bell and Whaley's typology, this was a kind of *masking* [5]. The practice was difficult to sustain; players frequently expressed frustration at the conflict between their desire to see what they were doing and their anticipation that doing so would give away their plans to the opponent. From observing and listening to players, it was apparent that this avoidance tactic took concentrated effort to maintain, and as such, it tended to lapse for increasing lengths of time as the game went on. In face-to-face communication, gaze averting is often attributed as a tell-tale sign of someone lying [14], but this was not detected in our study.

Gaze Scattering: Players went a step further than aversion, by actively scattering their gaze around the screen to give the impression that they were looking "everywhere". This tactic was intended to make it hard to distinguish moments of real planning from moments of arbitrary looking—similar to Bell and Whaley's concept of *dazzling* [5]. Gaze scattering also served as a kind of attack on the opponent's concentration. In Condition 2, all of the CA-GA players noted that the gaze visualisation distracted them from planning their own strategy under time pressure. In turn, players replicate this distraction for their opponent in Condition 3 by scattering their gaze, essentially "weaponising" the gaze visualisation.

Information Reduction: Players employed several tactics to reduce the amount of information their actions could give away. For example, players favoured drawing cards from the blind deck over drawing face-up cards, so that the opponent could not see what colours they were collecting. Other players took their turns as quickly as possible, minimising their opponent's time-frame for making inferences about their gaze and actions, causing the opponent to concentrate on their own plans instead.

Risk Reduction: Players adopted a more flexible strategy when they were aware that their gaze was being observed, to minimise the effect of being blocked by their opponent. For example, players chose to build across areas that offered the most alternative pathways, rather than going for a more direct and efficient route. Players who adopted this strategy typically tried not to claim any train routes for the first half of the game, and focused instead on collecting cards; this both reduced the information available to the opponent (gaze and in-game), and allowed the player to re-plan their route if the opponent's actions got in the way of their initial plan. Risk reduction strategies such as these ensured the player's intentions could not be pinned down, because they were left open to change.

Obstruction: Players sought to disrupt their opponent as a form of counter-attack, taking the focus away from their plans by playing aggressive moves such as taking cards and routes that they thought their opponent might need. The intended benefits of this were twofold. First, if done well, it forces the opponent to use up their resources to work around the blocking moves, which ideally left the opponent unable to complete their objectives by the game's end. Second, by forcing the opponent to play reactively, it neutralises the opponent's information advantage as the opponent would be less concerned about the gaze-tracked player's secret objectives. This was a high-risk strategy, as the player attempting it had less information available to them to know whether their aggressive moves were, in fact, obstructing their opponent's plans.

Simulation Deception Strategies

As well as hiding their true intentions, players sought to actively mislead their opponent through various kinds of *Gaze Misdirection* (3), a specific example of which was *Decoys* (16). Players also used *Gaze Camouflage* (4) strategies to create a false impression about the meaning of their actions.

Gaze Misdirection: Players attempted to give their opponent a false idea about what they were thinking by exhibiting behaviour that was consistent with an imagined alternative plan. For example, the player might stare at a route they think the opponent wants to build on, to scare them into thinking they will be blocked; this was intended to induce a degree of panic and to keep them from noticing the player's real plans. At times, players would take this further by alternating fixations between the route and a face-up card of the matching colour, to heighten the impression that the player was planning out their own construction, rather than idly looking at the map.

Decoys: A common sub-case of gaze misdirection was the use of decoy paths and is the most common deception strategy employed. Players who employed this strategy chose a set of cities far away from their real objectives, and repeatedly traced a path between them to give the impression that they were planning to build there. The decoy was usually chosen at the beginning of the game, shortly after the player had received their real objectives. Players typically watched out for their opponent building on their decoy path, and took this as confirmation that they had deceived the opponent. For the disinformation to be effective, however, the enemy must know how it is being accepted and interpreted by the target [22].

This strategy appears to be the most effective, particularly as opponents showed a degree of confirmation bias in their observations. Typically, the opponent expressed an early suspicion about one or two locations that the CA-GU player had looked at, and subsequently, they would notice any time the player's gaze overlapped that point, while being less alert to other areas that the player was looking at. This meant that opponents who were deceived by an early decoy often remained distracted by it, even after the CA-GU player has moved on from the decoy. Below is a chronological example from Session 17 ($P17_B$):

[03:09] *"She's really focusing on Pittsburgh."*

[05:57] *"I'm still convinced she's going to go Pittsburgh somehow. She won't stop looking at Pittsburgh."*

[08:39] *"She wants to do a loop down underneath. I just don't know how she plans to get to Pittsburgh after that."*

[09:02] *"Ok now she wants to get to Pittsburgh from here" [after opponent claimed Helena to Denver route]*

[11:49] *"I still think she is trying to get to Pittsburgh."*

[12:46] *"Maybe she didn't need to go Pittsburgh at all." [after opponent started to take new ticket cards]*

Gaze misdirections and decoys became less effective as the board filled up with claimed routes, as these were taken as more reliable evidence of the players' intentions than the gaze tracking. To counter this, there are instances where CA-GU players even spent resources to claim a route along their decoy path, just to sell the idea that they were planning to build there.

Gaze Camouflage: Players used elements of the game board as cover for their real point of attention. This corresponds to *repackaging* in Bell and Whaley's typology [5]. This strategy involved the player fixating for an extended period on routes that had already been claimed, to give the impression that they were considering this existing network, when in fact they were using their peripheral vision or brief side glances to plan a new path on nearby unclaimed routes. At other times this was done with elements outside the main game board, such as the cards around the outside. In some cases, the player appeared to be unaware that their face was turned towards the intended "cover point" but their eyes were still directed at their real goal, so the deception was unsuccessful.

DISCUSSION

Players demonstrated a deep understanding of how to utilise gaze visualisation and their added knowledge about their opponent's plan. This went beyond simply discerning the opponent's intended paths and blocking them. A common tactic was to plan the timing of an action based on its proximity to the opponent's gaze: if the player saw the opponent looking in the vicinity of a path they wanted, that path became the player's first objective; other paths were de-prioritised relative to their distance from the opponent's area of focus. If the opponent's gaze was far away from all of the player's goals, the player was more likely to build up resources and bide their time before claiming any routes, allowing them to play in an efficient manner that avoided signalling their own plans to the opponent. When players were confident in their predictions, they were able to plan for deception. For example, $P9_A$ predicted a multi-step path that their opponent would take, waited until the opponent had built along most of that path (confirming the prediction), and then claimed the final section at the last moment, forcing the opponent to take a long detour after they had invested many resources into the original route. Gaze unaware players were much less likely to engage in such aggressive tactics, as they were less confident that their actions would be in the to stop or disrupt their opponent.

The benefits of the gaze visualisation were offset by a cost in players' time and attention. Players reported that the visualisation was distracting, and made it hard to concentrate on planning their own strategy: *"If my task is only to predict my opponent's moves, that would be substantially an easier task, especially with the eye tracking. But when you try to make predictions and play the game with a time constraint, the cognitive load starts to build up."* [$P2_A$]. Accordingly, we observed that players who could see the gaze visualisation spoke less about their own strategy and more about their opponent. Players who could not see the visualisation were more likely to talk about the opponent's strategy in terms of potential risks and contingencies for their own strategy. Further, players speculated that the visualisation might be a net disadvantage in terms of winning the game due to its distracting nature, although most took a guess and mentioned that it would become more advantageous once players became accustomed to it.

The level of distraction may be partly attributable to the visualisation style. A few players commented that they would prefer a simple moving dot to the dynamic heatmap used in the study. The choice of the dynamic heatmap was informed by our prior study [34], in which it was the most accurately interpreted and second-most preferred visualisation style among nine formats compared. However, participants in that study were observers of a game rather than active players. It is possible that a less information-rich visualisation would be more manageable for players, who need to focus on developing their own plans as well as discerning those of an opponent. Moreover, the prior study showed substantial variations in preferences between participants. All in all, this suggests that it would be beneficial to give players some control over the gaze visualisation style, such as the ability to change its appearance or switch it on and off to manage the flow of information.

Non-live gaze visualisations could also help to avoid the distraction effects observed in this study. Mechanisms can be implemented to give each player a summary of where their opponent in an online match has looked, and for how long. For example, in *GeoGazemarks*, fixations were recorded and clustered to give a history of a user's points of interest to support free map exploration [19]. This is similar in function to the dynamic heatmap visualisation used in this study, although our heatmap provided a persistent summary only of gaze behaviour over the past few seconds; this persistent-summarising quality was one of the characteristics for which it was favoured in our prior study [34]. However, a non-live gaze visualisation would lose some of the affordances that provided for interesting gameplay opportunities found in our study, such as the use of *gaze scattering* strategy to distract an opponent.

While our study supports the general consensus of prior literature that gaze visualisations can be disruptive as well as informative, it also points to an opportunity for game designers to utilise this as a double-sided resource for players. We provide three examples of how this resource might be used as a "power up" in online multiplayer games. First, we can provide live information about where an opponent is looking, at the cost of distracting visual noise and the risk of being misled by false signals. This can also take the form of non-live gaze visualisations, giving the player a summary of the opponent's gaze but leaving open the possibility that the opponent had manipulated their gaze to be deceptive. Second, we can limit where gaze visualisations appear; either activated by the player, activated arbitrarily (such as on a timer), or activated by other gameplay systems (for example, only appearing in areas that the player has previously explored, similar to *fog of war* in concept). Allowing the player to see gaze visualisations in only part of the game could leave them with a strategic choice of whether to seek further gaze information, at the potential cost of distraction, or allow themselves to be oblivious to their opponent's gaze. Third, we can use awareness of gaze sharing as a game resource, so that under certain conditions a player is notified when their opponent can see their gaze, allowing them to undertake deception strategies.

Generalising the implications of this study to other types of games should be done with caution, however. *Ticket to Ride* was chosen as an appropriate game for gaze sharing as it is turn-based and both players see a largely identical screen, so they can watch each other taking turns. These qualities are common to many digital board games, but are not present in many popular genres of online games. For example, in a real-time strategy game such as *Starcraft*, players scroll across a game map that is larger than the boundaries of their screen. A gaze visualisation for this kind of game would have to be anchored to the in-game location that a player is observing, rather than just the coordinates on the screen. This would reduce the amount of time each player spent observing their opponents' gaze, as it would allow them to monitor gaze activity only in areas they are concerned with, or only in areas they have previously explored (as in fog of war). A player may deduce, for example, that their opponent is not launching an attack as long as their gaze activity is isolated to the area of their own base. However, in a real-time game such as this, we assume the level of distraction caused by gaze visualisation would be even more acute than in a turn-based game as players do not have time to sit and think.

Players were successful in devising deception strategies that reduced their opponent's prediction accuracy about their plans, but also found degrees of difficulty in maintaining them (in line with [40]). All of the strategies we observed were conceived independently by the players, without suggestions from the researchers, and the stated inspiration behind many of the strategies was the player's own experience of observing the gaze visualisation. Players were largely successful in converting their own experience into an accurate enough model of their opponent's thinking that they could implant a false belief about their strategy, or disrupt the prediction process in other ways. This demonstrates the application of *Theory of Mind*, as the *ability to deceive* is considered one of its hallmarks [28].

The effects of gaze visualisation were most pronounced in the early stage of the game. This was true both for the ability to make predictions and for the ability to deceive the opponent. At this stage, gaze data is a relatively clear signal, as there is little other information available in the form of routes claimed on the board. As the game progresses, deception through altered gaze behaviour becomes more difficult, as the accumulation of claimed routes on the board provides stronger evidence of intention than gaze behaviour. Claimed routes act as a costly signal due to the investment of resources involved, and so where there is a mismatch between routes and gaze (lack of correspondence, in Levine's terms [29]), the gaze information is ignored in favour of the route information.

This study extends prior work (e.g [34, 40]) by demonstrating that human subjects can make long-term predictions and employ deception given the ability to visualise gaze for longer durations. However, players commented that they lacked the attention and memory capacity to fully utilise the information that was theoretically available to them through the gaze visualisation. From our human observations, we found that players in our study ignored large areas of the board (e.g. whole left side) when they could see that their opponent was not looking at it. Based on their comments, it is apparent that this ability to triage the board on a wide scale was a substantial part of the competitive benefit players derived from gaze visualisation, comparable at least to the more fine-grained prediction of specific routes. We believe that future gaze-aware systems can do the same, by ignoring elements that are irrelevant to minimise computational cost. Our study also showed gaze enabled players to make earlier and more accurate predictions, which have positive implications for automated plan recognition systems [38]. Researchers have demonstrated that systems that can predict intentions based on gaze patterns [21], but beyond the question of how well computer systems can predict human intentions through gaze, there is the question of whether these systems could detect deception in human gaze behaviour, and distinguish "true" intentions from false.

Limitations

Whereas our previous studies have looked at gaze interpretation by passive observers (spectators) [34], this study involved gaze interpretation by active players. This allowed players to forestall their opponents' plans, potentially changing the outcome. As a result, a degree of human judgement was necessary to determine whether predictions were accurate at the time they were made, as players sometimes had to deviate from their original plans due to events in the game. Players used a combination of the gaze visualisation and in-game actions for their predictions, and we did not discriminate between guesses that were largely informed by one or the other.

During the study, players were prompted for their predictions only when they had been silent for a period of time, rather than at regular intervals; this helped to preserve the naturalistic flow of gameplay, but meant that prediction intervals varied between players and rounds. Asking for predictions at fixed intervals would standardise the results and allow a more standardised comparison between conditions and players, at the cost of a somewhat more artificial gameplay experience. Conversely, our results are subject to the experimental design—prompting players to make inferences about their opponents' strategy is likely to have influenced how they reasoned about the game, to at least a small extent.

CONCLUSION

In a lab study of an online strategy game enhanced with one-way shared gaze visualisation, we found that players were able use gaze visualisation to improve their ability to predict an opponent's intentions. Players were also able to alter their own gaze behaviour deliberately to hide their true intentions and convey false impressions, to a degree. We defined a typology of gaze-based deception strategies, which reflects the general theory of deception [5]. However, this deceptive behaviour required sustained effort, and players could not prevent some of their intentions from 'leaking' to the opponent through their gaze. Players found this gaze-based deception task to be challenging and engaging, and we have identified several avenues that may be fruitful for game design to explore.

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