Evaluating Gaze Communication in a Human-Robot Memory Game Setting

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***Abstract*—Gaze plays a crucial role in human interaction, thus also serving as a powerful non-verbal cue for human-robot interaction. In a memory game setting, we developed an interactive robot with two cameras as eyes to investigate how humans respond to robot gaze. Participants were presented with a sequence of colors, either through light-emitting diode (LED) instructions or robot gaze, and were tasked with reproducing them. We gathered N=40 participants spanning different demographic profiles and varying levels of prior robotic experience and conducted experiments to test several factors. We assessed participants' performance, understanding and confidence in both conditions, along with evaluating the game's efficacy and comfort. We found that the performance, understanding, and confidence of the participants were greater when given instructions by the LED. However, we found that the majority (75%) of participants found the game to be more engaging with the robot gaze, and that 85% of participants found that the robot gaze improves the social aspect of the game. Overall, while the instructions given by the robot gaze had a slightly greater mental load, the game played with the robot gaze was more preferable, engaging, and fun for the participants.**

***Keywords*—Human-Robot Interaction; Gaze Communication; Memory Game**

I. Introduction

Gaze is a very powerful form of non-verbal communication. Humans can easily interpret others' intentions and instructions just by their gaze. But what about the gaze of a robot? As robots become more common in our lives, it is important to know how people see and react to the way robots look at them and communicate with them [1]. This understanding is important in workplaces, care facilities [2], public spaces, and homes — particularly in contexts where robots are central, such as acting as teachers or guides [3], [4]. In [5] researchers investigated how humans perceive the robot's gaze when it is approaching them, and found that humans prefer the gaze to be directed at them, rather than at the robot's path. In [6], the robot detected the human's gaze and determined the focus, while in [7] the robots detected and replicated gaze communication to play a game. Gaze is also an important communication channel for turn-taking in games [8], [9].

The proposed work, similarly to [10] and [11], is based on the game of "Simon says". In this paper we use an in-house developed binocular robot to communicate instructions through its gaze. Participants arrange colored cards based on cues from either a light-emitting diode (LED) (control) or the robot's gaze (test). After the color sequence is evaluated by the robot, it provides feedback before advancing to the next sequence. Beyond assessing communication effectiveness, we also explore whether gaze interaction enhances game enjoyment [12], [13]. Research suggests that simply having a robot present may boost interest and enjoyment in the game without adding mental strain [14]. Furthermore, we also explore the pedagogical implications of a human-robot interaction as we aim to understand how individuals emotionally react to the robot gaze in a memory game setting, and, subsequently, improve robots' communication with humans. This study was primarily exploratory, focusing on gathering qualitative insights and observational data, helping identify patterns and generate hypotheses for future, more statistically rigorous studies.

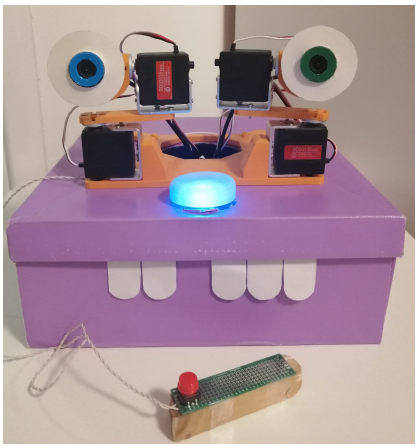


Figure 1. The developed robot and button used in the experiments. A single LED is installed under the robot's nose and used to play a sequence of different colors.

The paper is organized as follows. In Section II we give an overview of the robot design and software development, further explaining the methods used for the game-play. Section III presents the experimental setup and obtained results, while Section IV provides discussion and comments. Finally, Section V concludes the paper.

II. Methods

A. Robot Design

The robot used in the study, as seen in Fig.1, was the one developed within the scope of [15], where the goal was to

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develop a human-robot interaction platform that could communicate with gaze. The robot was given a cardboard shoe-box as the "body" to house electronic components. The cameras were mounted on four motors to enable gaze control in two degrees of freedom, and were decorated with a cardboard and colored paper to resemble eyes. The shape of the eyes is circular, which exaggerates their appearance while also having a practical purpose. It was shown that round eyes with big irises were the most effective in communicating gaze when designing robot eyes [16]. A single LED is encased in the "nose", serving as a color indicator and accuracy gauge. The simple design of the robot underpromises its capabilities, thus preventing the participants from having great expectations in robot's capabilities. In the end, the robot has some anthropomorphic features that aid its presentation without making it seem uncanny.

B. Software

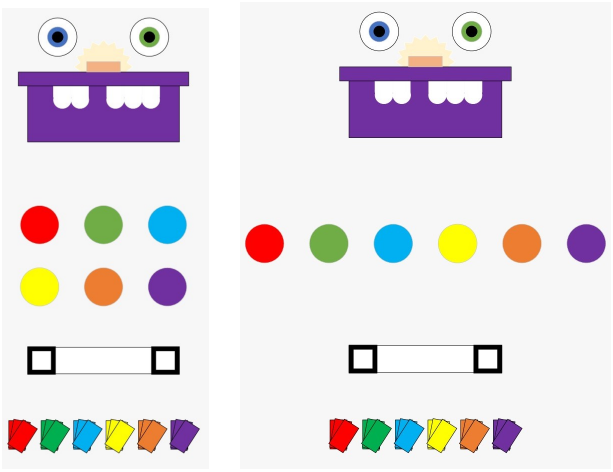
1) Game-loop: The game involves arranging colors across three-round levels. Success moves players forward, while failure prompts retries with new colors. Advancing through rounds unlocks higher levels, introducing more colors. The game ends when all rounds of the highest level are completed or players choose to exit. Game-play begins with random color generation, avoiding repeats, where colors are displayed through the LED or robot gaze. A timer starts after display, and players must arrange colors between markers.

2) Card Detection and Identification: In order for the robot to be able to direct its gaze at particular colors and check player's solution, a robust card detection and identification algorithm needed to be developed. The card detection process involves three main stages: initial color calibration, ArUco marker detection, and color segmentation. During color calibration, parameters are fine-tuned for accurate card segmentation, which allows adjustments to the HSV (hue, saturation and value) color values dynamically, enhancing robustness under varying lighting conditions[1]. ArUco markers, known for their unique identifiers, are used to extract the region of interest (ROI) in the image. Next, the precalculated color thresholds are applied to the ROI to obtain binary masks for each color. Contours within each mask are identified and filtered based on size, ensuring cards fall within expected dimensions. Finally, the recognized cards are stored and passed to the game loop for further processing.

III. Experiments

A. Setup

1) Technical arrangement: In the experimental setting, the robot and the participant are positioned across from each other. An interactive button is provided for participants to conclude game levels and confirm their choices. Circular colored papers are placed in front of the robot, while the participant faces a set of colored cards and a designated space for the chosen cards marked by ArUco markers. Two setup arrangements were used: the first 20 participants were examined using the 2x3 card setup, while the remaining 20 participants were examined using the 1x6 card setup. The examination setup can be seen in Fig. 2 where two different setups are shown.



(a) 2x3 colored circle setup

(b) 1x6 colored circle setup

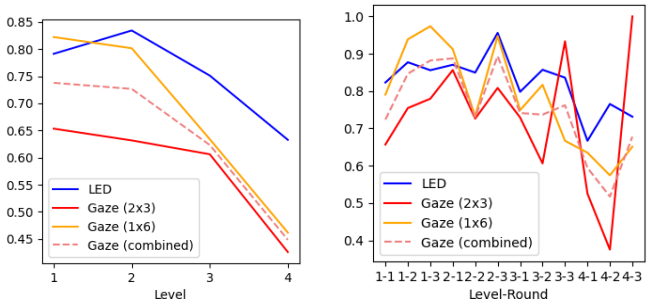
Figure 2. Examination setups

2) Examining stages: The participants underwent individual examinations in two distinct stages: the control condition and the test condition. All participants went through both experimental situations once (within-subject design), with no break between situations. The sequencing of these stages followed a randomized order, to ensure the stochasticity of the experiment. During both conditions, participants were tasked with memorizing and reproducing a set of color instructions by arranging a sequence of colored cards in front of them. In the control condition, color instructions were presented using LED lights to the participants, 1.5 seconds per color. Conversely, during the test condition, the robot guided participants through the sequence of colors by directing its gaze at the circular colored papers, in duration of 1.5 seconds for each color. When the participant was satisfied with their choice of cards, they signaled their decision by pressing the button. Subsequently, the accuracy of their responses was indicated by the LED light, with red signaling an incorrect response and green indicating a correct one. The stages were conducted at varying difficulty levels, ranging from memorizing sets of 3 cards to sets of 6 cards.

3) Participant Feedback: A group of **N=40** people, spanning different demographic profiles[2], took part in the experiment. After the experiment, participants filled out a questionnaire. The questions covered how well they understood the instructions, their assessment of the efficacy of the robot's communication for both the control and test conditions, their feelings about interacting with the robot, and how much

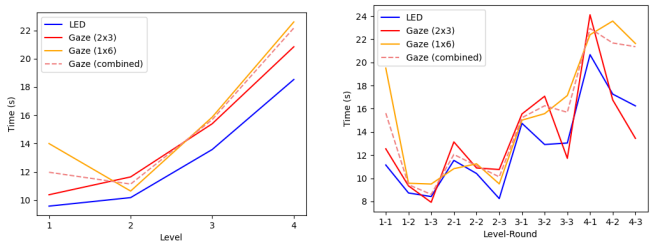
[1]As opposed to the RGB (red, green, blue) color model, which makes color segmentation under varying lighting conditions more challenging.

[2]Most of the participants were students from the University of Zagreb, from varying faculties, as well as friends and family thereof spanning across different age groups.



(a) Average accuracy per level (b) Average accuracy per round

Figure 3. Average accuracies



(a) Average round time per level. (b) Average round time per individual round

Figure 4. Average round time

they enjoyed the game, among other aspects. No participants dropped out, and all the questionnaire answers were valid. The experiments took place over several sessions at the Faculty of Electrical Engineering and Computing, University of Zagreb.

B. Results

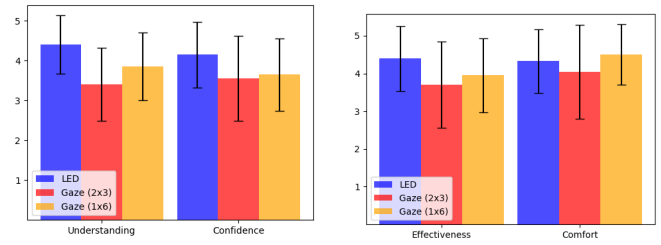
The average participant accuracy[3] per level and round on different card setups and average accuracy on both setups combined can be seen in Fig. 3. The combined average accuracy for the control condition (LED) was **69.42%**. On the test condition (robot gaze), the average accuracy for the 2x3 setup was **57.18%**, while for the 1x6 setup it was **59.59%**.

Average round time per level and per individual round can be seen in Fig. 4. Participant responses regarding instruction understanding and their confidence afterwards can be seen in Fig. 5a, for both the control and test conditions. The participant's estimation on how efficient and comfortable both game conditions are is shown in Fig. 5b.

The following was gathered from the questionnaire answers:

- **77.5%** found adapting to the robot gaze easy or very easy.
- **27.5%** found following the robot gaze distracting.
- **2.5%** found the robot scary or threatening.
- **75%** found the game to be more fun with the robot gaze.
- **85.0%** found that the robot gaze improves the social aspect of the game.
- **70%** of participants on the 1x6 setup were more open to future interactions with gaze-communicating robots than those on the 2x3 setup, who amounted to **55%**.

[3]A round is correct if all of the sequence colors are in the right order. The participant's sequence is either correct or incorrect (no partial correctness).



(a) Understanding and confidence in LED and robot gaze (b) Game effectiveness and comfort in LED and robot gaze

Figure 5. Participants' feedback on different game conditions

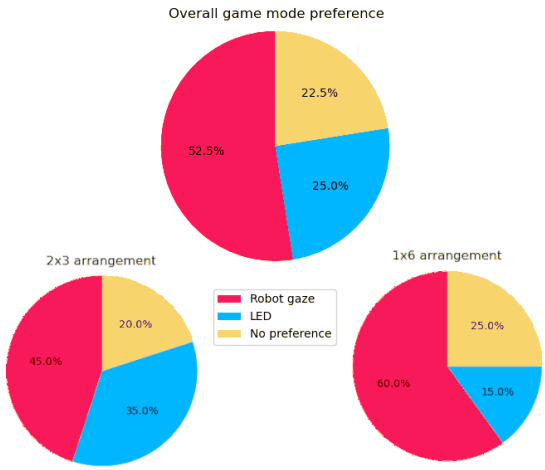


Figure 6. Game mode preferences

- **45%** of participants on the 1x6 setup understood gaze instructions more than or equally to the LED instructions, as opposed to **30%** on the 2x3 setup.
- **65%** of participants playing on the 1x6 setup were more or equally confident in their answers after gaze instructions than after LED instructions, as opposed to **35%** on the 2x3 setup.
- **55%** of participants playing on the 1x6 setup found the gaze instructions to be more or equally suited for the game than the LED instructions, as opposed to **40%** on the 2x3 setup.
- **85%** of participants playing on the 1x6 setup found the gaze instructions to be more or equally comfortable than the LED instructions, as opposed to **60%** on the 2x3 setup.

The game mode preference charts are shown in Fig. 6.

IV. Discussion

As seen in Fig. 3, the average accuracy in the control condition (LED) is higher than in the test conditions (robot gaze). As suggested by many participants, more attention needs to be paid while observing the robot gaze in the test condition, which is also supported by the greater average round time in Fig. 4. We can see in Fig. 4a that the average time per round at a certain level increases as the levels progress. This can also be seen in Fig. 4b, but it is interesting to note that the average round time decreases during individual

levels. This could be explained by the participants getting used to a newly added color, thus needing less time for the sequence. From the greater average round time in Fig. 4 and the participant questionnaire responses regarding instruction understanding and confidence in Fig. 5a we can infer that the test condition produces a slightly greater mental load while playing. Even though the participant performance is worse in the test condition, as the results of the questionnaire show, a majority of the participants found the game to be more fun with the robot's gaze and that it improves the social aspect of the game, which is a key point that we aimed to answer.

The arrangement of the colored circles that the robot gazes at greatly affects how humans perceive its gaze. Between the two gaze setups, participants performed better on the 1x6 setup, which is similar to what was done in [16]. The less ambiguous setup (1x6) increased the participants' accuracy (Fig. 3), understanding of instructions, confidence in answers, and perceived comfort and effectiveness of the game (Fig. 5). Only **2.5%** of participants found the robot scary or threatening, which is very important for human-robot interaction, especially for pedagogical applications.

The impact of the arrangement of colors can also be seen in the overall game mode preference charts in Fig. 6. When faced with less ambiguity in the robot gaze communication, participants prefer the gaze communication over the LED despite the gaze communication having a slightly greater mental load and with their answers being less accurate. An ideal arrangement of colored circles would be to order them in a semicircle around the robot, so the difference of angles between each color is the same.

An advantage of gaze communication, which some participants reported, is that people who have trouble differentiating colors (such as in cases of color blindness) can more easily infer which color to pick based on the direction of the robot's gaze. This is applicable to other cases where certain objects in the shared environment need to be brought to the human's attention, and when other channels of communication (such as colors through LEDs, text through screens, or speech through speakers) might be hard to interpret by some people.

V. Conclusion

In this paper, we investigated the effectiveness of robot gaze as a means of communication in the context of human-robot interaction. For this we utilised a binocular robot to communicate color sequences to the player, either by directing it's gaze at colored circles (test conditions) or by changing the color of an LED (control condition). After receiving the sequence, the player needs to reproduce it by arranging colored cards between two ArUco markers. The robot then provides feedback on the arranged sequence. We have gathered **N=40** participants who played both conditions (within-subject design) with counterbalance to the order of condition exposure.

The instructions given by robot gaze had a slightly greater mental load. This could be attributed to more attention being paid to the direction of the robot's gaze. Moreover, the arrangement of the colored cards affects performance, understanding of instructions, confidence in answers and perceived effectiveness and comfort of the game. We have shown that the 1x6 arrangement improves these factors when compared to the 2x3 arrangement. Overall, while not as good as the LED, robot gaze proved to be an effective way of communicating a sequence of colors in this particular game, while being preferable and more engaging.

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