Unconscious and Intentional Human Cues for Designing Expressive Robot-Arm Motions

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***Abstract*—We investigate motion imitation for expressive robot-arm behavior in the imperfect-information game *Geister*. We first analyze human piece-moving motions in two modes—natural gameplay (unconscious tendencies) and instructed expressions (intentional cues)—and find subtle late-phase differences in the former versus clearer, more interpretable cues in the latter. Guided by these findings, we design phase-specific robot motions (varying speed and stop duration) and evaluate observer impressions under two presentation modalities: a physical robot and recorded video. Results show that late-phase timing, especially withdrawal, strongly shapes impressions, and that physical embodiment amplifies these effects relative to video. We discuss implications for motion design, highlighting selective use of intentional human cues and prioritization of late-phase timing with in-person evaluation.**

***Index Terms*—Robot Arm, Unconscious and Intentional Human Behavior Game Piece manipulation, Geister**

I. Introduction

Robots are increasingly integrated into daily life, operating in contexts such as schools, hospitals, and shopping malls. Social robots often rely on explicit expressive channels (e.g., facial expressions, gestures) to communicate internal states, whereas task-oriented robots, such as cleaning robots or robotic arms, frequently lack such mechanisms. While task efficiency is crucial, prior research has indicated that the absence of expressive behaviors may hinder user acceptance and satisfaction [1], [2]. Furthermore, conveying a robot's internal state has been argued to improve coordination and trust in collaborative tasks [3].

A promising approach for enabling robots to express internal states is through motion imitation. Designing robot movements based on human motion patterns can lead to more natural and intuitive communication [4]–[6]. Board games, with their well-defined rules and constrained action spaces, have often been used in human–robot interaction (HRI) research as reproducible testbeds for studying non-verbal expression [7], [8].

We employ the imperfect-information game *Geister*, which is suitable because piece intentions are explicitly defined: red pieces (evil ghosts) are intended to be captured by the opponent, while blue pieces (good ghosts) must be protected. This allows us to associate differences in internal state with differences in human movements during piece manipulation. Our previous work in this setting investigated impression changes caused by inserting a pause into robot-arm motions [9], but left open how human-derived timing (speed and stop duration) can be leveraged to design arm motions that communicate internal states.

Fig. 1. Pieces and Board of the Simplified Geister Game

In this research, we analyze human arm movements in simplified *Geister* (Fig. 1), focusing on phase-specific variations in speed and stop duration, and investigate how these findings can inform robot-arm motion design. Specifically, we compare natural movements during gameplay with intentionally expressed movements, and evaluate observer impressions of robot-arm motions in both physical and video presentation conditions.

A subset of these results was previously reported [10], covering the analysis of natural human movements during gameplay (Exp. 1-1) and the evaluation of robot motions derived from those movements (Exp. 2-1). In this paper, we extend those findings by reporting the full set of experiments, including the analysis of intentionally expressed piece-moving motions to communicate internal states (Exp. 1-2), and by comparing observer impressions when the same robot motions are observed physically versus via video (Exp. 2-2).

Although our experiments use a game context, conveying internal states through motion is also essential in broader collaborative HRI, where it can strengthen trust and task efficiency [11].

II. Simplified Geister

We use a simplified version of *Geister* to shorten matches and facilitate data collection of game-piece manipulation while preserving core game characteristics. The board is reduced from 6×6 to 3×3, and each player has three pieces (two blue [good] and one red [evil]). Prior work reports that

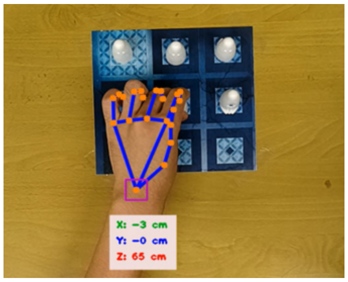


Fig. 2. Example of Data Acquisition

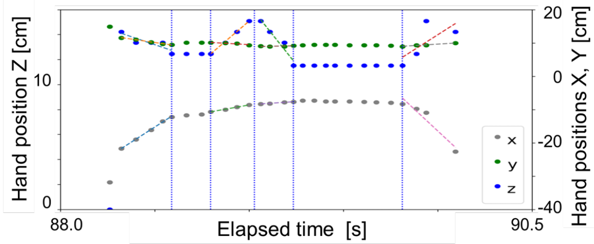


Fig. 3. Representative wrist trajectory during game-piece manipulation. Elapsed time (s) on the horizontal axis; 3D hand position on the vertical plots with x = front–back, y = left–right, and z = height from the board. Blue dashed lines indicate the six phases (Phase 1–6).

such reductions minimally affect fundamental properties [12]. Figure 1 shows the setup. The rules are:

- Win by capturing both of the opponent's blue pieces;
- Lose by capturing the opponent's red piece;
- Win by escaping a blue piece through an escape square.

III. Experiment 1: Human Movement Analysis

We first describe an experiment conducted to analyze human arm movements when moving two types of pieces. This experiment aims to analyze the effects of internal state differences on piece-moving behaviors. Experiment 1 consists of two experiments: Exp. 1-1, which involves recording and analyzing piece-moving motions during an actual game, and Exp. 1-2, which involves capturing and analyzing intentionally expressed movements. Through these experiments, we aim to investigate the relationship between the internal states and arm movements and the differences between natural and intentionally expressed movements.

A. Experimental Setup

We used a depth camera (Luxonis OAK-D S2) and a desktop PC (GALLERIA RM7C-R35T) to capture participants' arm movements. Figure 2 illustrates an example of the data acquisition. Although the system can capture finger movements, only wrist positions were recorded to represent arm motions.

The same setup was applied in both Exp. 1-1 (natural gameplay) and Exp. 1-2 (intentional expression). Recorded trajectories were later segmented into six phases (approach, grasp, lift, placement, pre-release stop, release), and phase-specific features such as speed and stop duration were extracted for analysis.

B. Exp. 1-1: Natural Piece-Moving Motions

To examine natural movement tendencies, participants played the simplified Geister in pairs while their wrist trajectories were recorded. Four male participants in their 20s took part, and a total of ten matches were collected. Each match lasted about 135 seconds on average. All participants had prior experience with the game.

Results: Figure 3 shows a representative wrist trajectory during piece manipulation. Based on 29 forward moves (blue: 18; red: 11), we segmented each move into six phases (Phase 1–6; see Fig. 3). For each phase we extracted speed and stop duration, and conducted paired t-tests. Blue-piece moves tended to be slower during placement (Phase 4, $p < .1$), showed shorter stops before release (Phase 5, $p < .05$), and exhibited faster release (Phase 6, $p < .1$). Taken together, these phase-specific differences suggest that intent-relevant timing cues are concentrated in the later phases, providing useful priors for robot-arm motion design.

C. Exp. 1-2: Intentionally Expressed Piece-Moving Motions

In addition to natural gameplay, we conducted an experiment to capture intentionally expressed motions. Eight male participants in their 20s (independent from Exp. 1-1) were asked to move pieces forward while explicitly conveying the following intentions:

- Moving a red piece: Perform a motion that conveys "wanting the opponent to capture the piece."
- Moving a blue piece: Perform a motion that conveys "not wanting the opponent to capture the piece."

Verbal informed consent was obtained from all participants before the experiment. They then performed the instructed movements once for both red and blue pieces. Participants took enough time to consider their movements before performing the motions, and then they performed the motions, and the motions were recorded.

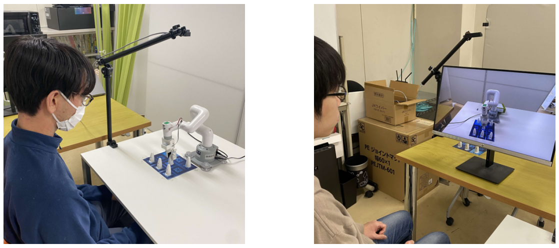
Results: Because the instructions were subjective, large individual differences were observed. Statistical testing was therefore not applied; instead, we identified trends by counting participants whose motion parameters (speed or stop duration) differed by a factor of two or more between red and blue pieces. Several phases showed consistent tendencies across participants (e.g., faster approach in Phase 1 for blue pieces, longer stop duration in Phase 2 for red pieces). The observed trends are summarized in Table I. These patterns indicate that when explicitly asked to express internal states, participants tended to exaggerate certain phases, producing clearer motion cues than in natural gameplay.

D. Discussion of Experiment 1

Comparing Exp. 1-1 and Exp. 1-2 highlights the difference between unconscious and intentional expression. In natural gameplay, psychological deception and strategic considerations often led players to mask their internal states, reducing the observable differences between red and blue pieces. Nevertheless, subtle tendencies still emerged in later phases,

TABLE I
OBSERVED TRENDS IN EXP. 1-2

Phase		Observed Trend
1	Speed	Blue > Red (majority)
2	Duration	Blue < Red (majority)
3	Speed	Blue > Red / Blue < Red (split)
4	Speed	Blue > Red / Blue < Red (split)
5	Duration	Blue > Red / Blue < Red (split)
6	Speed	Blue < Red (majority)



(a) Robot Condition (b) Video Condition

Fig. 4. Experimental Environments for Each Presentation Condition

suggesting unconscious hesitation or confidence. In contrast, intentional expression produced clearer and more easily interpretable differences, although with high variability across individuals.

These findings suggest that while unconscious human patterns may inspire subtle robot motions, intentionally exaggerated cues may be more effective for conveying internal states to observers. This distinction motivates the subsequent design of robot-arm motions and their evaluation in Experiment 2.

IV. EXPERIMENT 2: ROBOT MOTION EVALUATION

A. System Configuration

The robot arm used in this experiment was the myCobot 280M5 (Elephant Robotics), equipped with a dedicated gripper for piece manipulation. A desktop PC (GALLERIA RM7C-R35T) controlled both the robot arm and a depth camera (Luxonis OAK-D S2).

We implemented seven robot-arm motion patterns: one baseline condition (slow movements with long stops) and six comparative conditions, each modifying a single phase of the motion by either increasing speed or shortening stop duration. In all cases, the motion involved advancing a piece one square forward from the center of the board's front row.

The experimental environments for both the robot presentation condition and video presentation condition are illustrated in Figure 4.

B. Exp. 2-1: Robot Condition

In this condition, participants directly observed the myCobot performing the seven motion patterns. Ten participants (5 male, 5 female; aged 20–30) took part. Each participant observed 12 trials (baseline vs. one comparative movement), and after each trial completed a questionnaire consisting of the Godspeed subscales (Anthropomorphism, Animacy, Perceived Intelligence) and four task-specific items (confidence, hesitation, rushedness, intention-to-be-captured).

Results: Paired t-tests compared baseline and phase-modified motions. Significant effects emerged as follows: (i) *faster reaching* (Phase 1) increased perceived confidence ($p < .1$); (ii) a *longer stop before lifting* (Phase 2) increased perceived intelligence ($p < .05$); (iii) *faster placement* (Phase 4) tended to be judged as rushed; and (iv) *faster withdrawal* (Phase 6) increased anthropomorphism ($p < .1$) and animacy ($p < .05$).

Overall, these results suggest that later phases, especially withdrawal timing, exerted stronger influences on impression formation, whereas earlier phases had more limited or nuanced effects.

C. Exp. 2-2: Video Condition

In this condition, participants watched recorded videos of the same robot motions instead of observing the physical robot. The same participants completed the questionnaire after each trial.

Results: Paired t-tests compared baseline and phase-modified motions. Compared to the robot condition, effects on the GQS subscales (Anthropomorphism, Animacy, Perceived Intelligence) were attenuated; no subscale-level differences reached significance. At the item level, however, phase-specific manipulations yielded notable effects: (i) *faster lifting* (Phase 3) increased perceived confidence ($p < .1$); (ii) *faster placement* (Phase 4) tended to be judged as more hesitant; and (iii) *faster withdrawal* (Phase 6) increased intention-to-be-captured ($p < .05$).

These results indicate that video presentation weakens global impression changes observed with the physical robot, although certain phase cues remain interpretable.

D. Discussion of Experiment 2

Comparing the two conditions shows that the physical presence of the robot substantially amplified impression changes. Significant differences on the Godspeed subscales were observed mainly in the robot condition, whereas video presentation produced weaker and more fragmented effects. This pattern is consistent with prior work suggesting that embodied presence enhances human perception of robot behaviors [**?**], [13], [14].

Taken together, these findings reinforce two points:

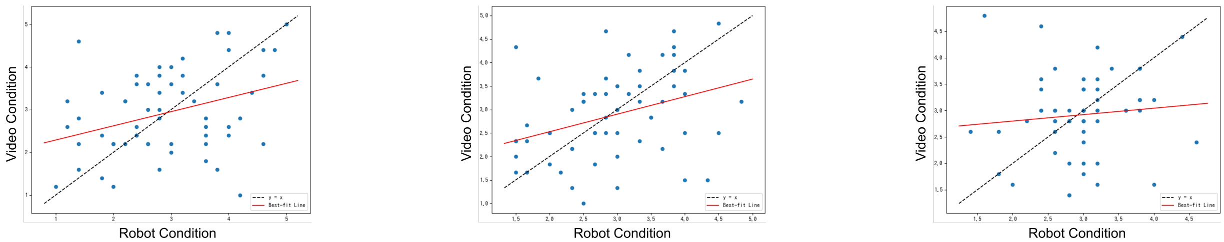
- **Phase-specific timing**—especially in the final withdrawal phase—plays a key role in conveying internal states.
- **Presentation modality matters**—robot movements observed in physical form have stronger and more coherent impacts than those shown via video.

Practically, this implies that evaluations of expressive robot motion should prioritize in-person studies (or, at minimum, account for embodiment effects) and focus design effort on late-phase timing parameters.

V. DISCUSSION

A. Unconscious vs. Intentional Human Movements

Experiment 1-1 revealed subtle but consistent differences in later phases of natural gameplay motions: slower placement, shorter pre-release stops, and faster withdrawal when moving



(a) "Anthropomorphism" scores (b) "Animacy" scores (c) "Perceived Intelligence" scores

Fig. 5. Distribution of GQS Scores in Robot and Video Presentation Conditions

blue pieces compared to red pieces. These tendencies can be interpreted as unconscious hesitation or avoidance under risk. However, strategic deception in Geister likely suppressed overt cues, making the differences modest [15].

In contrast, Experiment 1-2 showed that when participants were explicitly asked to convey "wanting" or "not wanting" capture, their motions became exaggerated, yielding cues that are easier to interpret—consistent with legible-motion accounts and timing-based expressivity [**?**], [**?**]. In addition, phase-specific differences were clearer, with substantial inter-individual variability. This suggests that unconscious human behaviors may not always provide sufficiently interpretable cues for robot motion design, whereas intentionally emphasized cues may serve as more reliable design elements. For expressive robot motion, therefore, combining insights from both natural and intentional human behaviors could provide a balance between subtlety and clarity.

B. Physical Robot vs. Video Presentation

In the robot presentation condition, several significant ($p < .05$) and marginal ($p < .1$) differences were observed between the baseline and phase-modified motions on the three GQS subscales (Anthropomorphism, Animacy, and Perceived Intelligence). In contrast, no such differences were observed in the video presentation condition.

Figure 5 plots the distribution of GQS subscale scores for each comparative movement under both conditions. The horizontal axis represents scores in the robot condition, while the vertical axis represents scores in the video condition. Red lines indicate regression fits, and the black dashed line represents the identity line ($y = x$). The correlation coefficients were $r = 0.342$ for Anthropomorphism, $r = 0.350$ for Animacy, and $r = 0.103$ for Perceived Intelligence, suggesting weak positive correlations for the first two and virtually no correlation for the latter. Evaluation items outside the GQS scales also showed little correspondence between the two conditions.

These results indicate that the physical presence of the robot substantially influences impression formation compared to viewing the same motion through video. This finding aligns with prior work on modality effects in robot evaluation [13], [14], [16] and underscores the importance of embodiment in assessing expressive robot motions.

C. Implications for Robot Motion Design

Taken together, our findings suggest three key implications for the design of expressive robot-arm motions:

- **Phase-specific focus**: Timing in the later phases of motion—particularly during withdrawal—has a disproportionate impact on impression formation and should therefore be prioritized in motion design.
- **Cue selection**: Unconscious human motion patterns reveal subtle but often ambiguous tendencies, whereas intentional expressions provide more explicit and more interpretable cues. Designers may need to amplify such cues when implementing expressive robot motions selectively.
- **Embodiment effect**: Physical embodiment substantially enhances the interpretability of motion cues. Systems intended for real-world HRI should be evaluated in physical contexts rather than relying solely on video-based assessments.

VI. Conclusion

This study analyzed human arm movements in the imperfect-information game *Geister* and examined how phase-specific variations in robot piece-moving motions shape observers' impressions. Natural gameplay reflected unconscious tendencies, whereas intentionally expressed movements provided clearer, more interpretable cues. We also compared physical versus video presentations, finding modality-dependent differences in impression formation.

Our results suggest that consciously emphasized human actions are effective design cues for expressive robot motions, while unconscious tendencies are subtler and less consistent. Physical embodiment further amplifies the interpretability of motion cues relative to video.

Limitations include variability that hindered detailed statistical analysis of intentional movements and the manipulation of only one motion phase at a time. Future work should refine instructions, enlarge the participant pool, and study combined phase manipulations to clarify how timing cues jointly influence impressions.

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