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# Influence of a Partner's Behavioral Process on the Sense of Joint Agency During Collaborative Task

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## Abstract

We frequently interact with others daily and experience a sense of joint agency—the feeling of performing an action together. Recent studies suggest that this sense of joint agency is influenced by the perceived "human-likeness" of partner. This study examined how a partner's behavioral process, specifically adaptation and fluctuation, affects joint agency in a cooperative task mediated by human-likeness. Participants completed a cursor-tracing task simulating collaboration, with cursor movement determined by combining their input with pre-recorded data. In this experiment, adaptation was approximated by preprogrammed changes in the cursor movement. The results revealed that adaptation enhanced joint agency, whereas fluctuation had no significant effect. Human-likeness is thus positively correlated with joint agency. Moreover, individual traits such as extraversion and attachment shaped these perceptions in unexpected ways. Poor task performance increases joint agency. These findings contribute to this field by identifying factors that influence the sense of joint agency.

**Keywords:** joint agency; human-likeness; behavioral process; extraversion; attachment; task performance

## Introduction

The sense of agency (SoA) refers to the feeling of controlling one's own actions (Gallagher, 2000), while the sense of joint agency (SoJA) refers to the sense that "we did it" in joint action (Pacherie, 2012). Human-likeness has been identified as a critical factor in evoking joint agency, particularly in interactions with artificial agents.

Sahaï et al. (2023) demonstrated that interacting with a humanoid robot elicited a stronger sense of agency compared to a servo motor, suggesting that human-like appearance enhances both self and joint agency. Similarly, Navare et al. (2024) reported that participants experienced greater joint agency when a humanoid robot was perceived as an intentional entity, emphasizing the role of intentionality attribution. Intentionality is closely associated with human-like traits; Ciardo, De Tommaso, & Wykowska (2021) found that robots exhibiting human-like errors were more likely to be perceived as intentional, while Martini, Gonzalez, & Wiese (2016) showed that agents with human-like characteristics were more readily attributed with a mind. Collectively, these findings underscore the connection between human-likeness and joint agency.

Although previous studies have focused on human-like appearance and intentionality attribution, little is known about how human-like *behavior* influences joint agency. This study examined the role of behavioral process on the sense of joint agency.

Adaptation is an action that humans perform unconsciously (Xu et al., 2012). Xu et al. (2009) observed mutual adaptation in paired participants communicating through gestures, where individuals adjusted their actions based on their partner's behavior. Therefore, adaptation to the actions of another person is perceived as a hallmark of human-like behavior. Fluctuation in behavior is another critical indicator of human-likeness. Ciardo, De Tommaso, & Wykowska (2022) showed that participants could distinguish humans from computer programs based on response time variability, emphasizing the importance of behavioral fluctuations in perceiving human-like traits.

Building on these insights, this study investigated how a partner's behavioral process, including adaptation and fluctuation, influences the sense of joint agency. Participants performed a task designed to simulate collaboration by controlling a cursor with a joystick, and its movement was determined by combining their input with pre-recorded data. This setup created the impression of collaborating with a partner even though no actual partner was present.

Adaptation was simulated by manipulating a factor called "change," which involved gradually increasing the proportion



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of the participant's input reflected in the cursor's movement (α value). This incremental adjustment was expected to give the impression that the partner was aligning their behavior with that of the participant. Fluctuation was introduced by slightly increasing or decreasing the α value on a trial-by-trial basis, simulating behavioral fluctuation in the partner's actions.

This study tested the hypothesis that behavioral cues—specifically adaptation (change) and fluctuation—enhance the perception of human-likeness, which in turn strengthens the sense of joint agency. The hypothesized relationships among these factors, human-likeness. and joint agency are shown in Figure 1A. To test this hypothesis, a linear mixed-effects model was employed to analyze the effects of these two factors on joint agency, and their mediated effects through human-likeness were examined using path analysis.

## Methods

### Participants

Thirty-six individuals (23 males, 13 females; mean age = 23.4 years, *SD* = 5.3 years, with 2 participants not reporting their age) took part in the study. The required sample size was estimated using G*Power 3.1, based on a two-factor repeated-measures ANOVA with an effect size of $f = 0.20$, a significance level of $\alpha = 0.05$, and a power of 0.80. Since the effect size was unknown, a small-to-medium effect size was chosen based on Cohen (1992), resulting in a minimum sample size of 36. Although the power analysis was based on ANOVA, the actual data were analyzed using a linear mixed-effects model. Additionally, path analysis was conducted independently of the power analysis.

Before participating, all participants received detailed information about the study and provided written informed consent. The Ethics Committee at the university to which authors belong approved this study.

### Experimental Task

The task was based on Ohata et al. (2020), which explored the sense of agency through trials with randomly set α values. Expanding on this, the current study introduced four experimental conditions by manipulating temporal changes in α. The task was programmed and executed using PsychoPy (version 2024.1.4) (Peirce et al., 2019).

Participants traced a circle on the screen using a cursor controlled by a joystick. The experimental task screen is shown in Figure 1B. The cursor coordinates were calculated using the following equation:

$$(X, Y) = (x, y) \times (1 - \alpha) + (x', y') \times \alpha$$

Here, (X, Y) represents the cursor's coordinates, (x, y) are the coordinates from the pre-recorded data, (x', y') are the participant's joystick inputs, and α is the proportion of the participant's input reflected in the cursor's movement. The

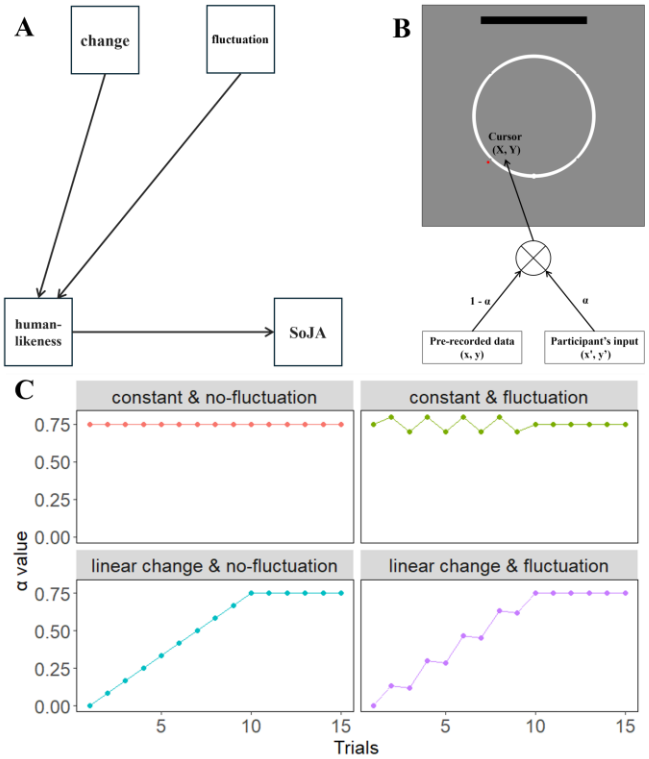


Figure 1: (A) Diagram illustrating the hypothesis of this study (B) The experimental task screen (C) Temporal changes in α values across the four conditions

participant's joystick inputs, and α is the proportion of the participant's input reflected in the cursor's movement. The author created the pre-recorded data by operating the joystick.

The experiment comprised four conditions defined by two within-participant factors. The temporal changes in α for each condition are illustrated in Figure 1C. Each condition included 15 trials, with the final five trials fixed at $\alpha = 0.75$, designed to evaluate the ultimate effects of the experimental conditions on joint agency.

The first factor, "change," consisted of constant and linear change conditions. In the constant condition, α was fixed at 0.75 throughout the trials. Under the linear change condition, α increases linearly from 0.0 to 0.75. This manipulation aimed to simulate "adaptation" in the partner's behavior, giving the impression that the partner was adjusting their behavior to align with the participant's actions.

The second factor, "fluctuation," consisted of no-fluctuation and fluctuation conditions. In the fluctuation condition, 0.05 was added to α in even-numbered trials and subtracted in odd-numbered trials. This condition introduced trial-by-trial fluctuations in the proportion of the participant's input reflected in the cursor movement, creating the impression of behavioral fluctuation.

To avoid bias, participants were instructed to collaborate with a "partner" to trace the circle without being informed whether the partner was human or a program. A black time

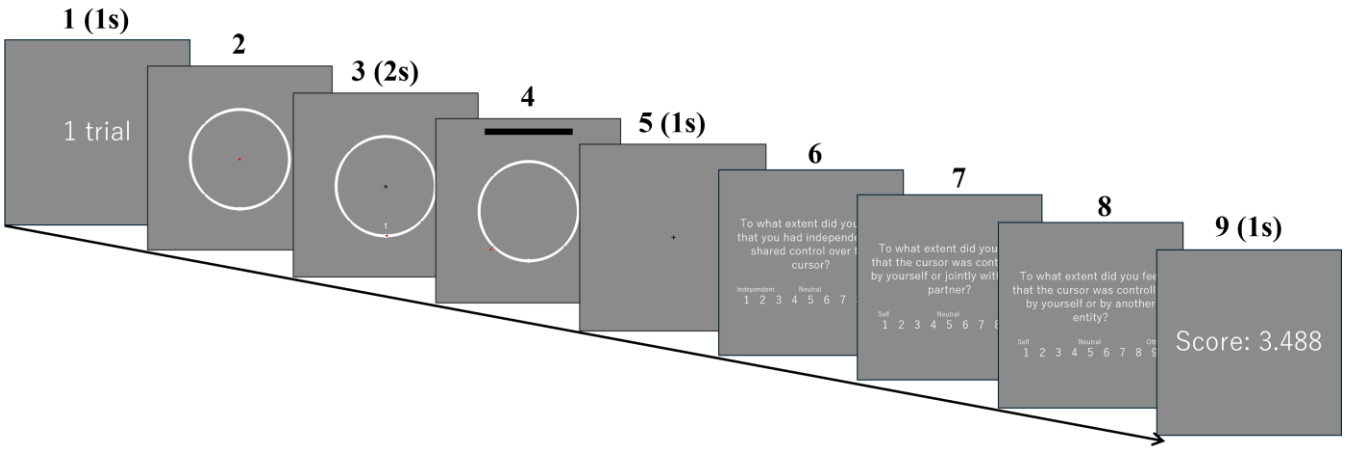


Figure 2: The flow of a single trial (timing in parentheses). The images containing text are not actual experimental screens.

bar that gradually shortened over the trial was displayed above the circle. Participants were required to complete one rotation by the time the bar disappeared to standardize tracing speed across participants.

## Procedure

The flowchart of a single trial is shown in Fig. 2. Each trial began with the trial number displayed for one second (1), followed by an initial screen with a white circle and red dot at its center (2). Participants moved the red dot to the starting point at the bottom of the circle, triggering a two-second countdown (3). After holding the cursor at its starting point until the countdown ended, the participants traced the circle in approximately 10 seconds, synchronized with a time bar (4). Subsequently, a fixation point was displayed for one second (5), followed by a questionnaire assessing the sense of joint agency (6, 7) and agency (8). Finally, the error, defined as the difference between the cursor trajectory and circle, was displayed for one second (9).The questions related to agency were rated on a 9-point Likert scale:

1. "To what extent did you feel that you had independent or shared control over the cursor?" (1: Independent – 5: Neutral – 9: Shared) (Shiraishi & Shimada, 2021) – referred to as "SoJA1."
2. "To what extent did you feel that the cursor was controlled by yourself or jointly with your partner?" (1: Self – 5: Neutral – 9: Joint) (Shiraishi & Shimada, 2021) – referred to as "SoJA2."
3. "To what extent did you feel that the cursor was controlled by yourself or by another entity?" (1: Self–5: Neutral–9: Other) (Ohata et al., 2020) – referred to as "SoA."

SoJA1 and SoJA2 assessed joint agency using two distinct formats. Measuring SoA was also considered important due to its known relationship with system acceptability (Vantrepotte et al., 2022). However, this study primarily focused on joint agency, with no attention given to findings related to SoA.

After each set of trials, participants answered four additional questions on a 7-point Likert scale.

1. "To what extent did you feel that your partner considered your actions?" (Osawa, Kawagoe, Sato & Kato, 2021)
2. "To what extent did you feel your partner was human or a program?" This question was key to assessing human-likeness in the hypothesis and is called "program-likeness."
3. "To what extent was the object control comfortable?" (Matsumoto, 2021)
4. "To what extent did you feel like a leader or follower in controlling the object?"

Following the experiment, participants completed 10-item extraversion and attachment scales (Fujishima, Yamada, & Tsuji, 2005) using a 5-point Likert scale. Previous research suggests that individuals with high extraversion, agreeableness are likelier to experience "united agency" (Trần, Cummings, & Loehr, 2024). Thus, extraversion and attachment were analyzed for their effects on joint agency.

## Data Analysis

A linear mixed-effects model (LMM) using the restricted maximum likelihood method was employed to examine the effects of change and fluctuation on agency. The goal was to assess the main effects and interactions of these factors while controlling for the potential influences of task performance and perceived human-likeness. LMM was chosen over repeated-measures ANOVA due to its flexibility in accounting for both fixed and random effects, as well as its ability to incorporate covariates and reflect the hierarchical structure of the data, including individual differences and task execution order.

Data from the final five trials of each condition, where the α value was fixed at 0.75, were analyzed without further pre-

processing. The dependent variables were SoJA1, SoJA2, and SoA. The fixed effects included in the model are changes, fluctuations, interactions, error, and program-likeness. To capture individual differences and execution order effects, a hierarchical structure was modeled with "participant ID" nested within task execution order as a random effect.

Path analysis using the maximum likelihood estimation method was conducted to explore the structural relationships between change, fluctuation, and agency, mediated by perceived human-likeness. While LMM was used to assess the effects of experimental factors on agency, path analysis was additionally employed to investigate the underlying causal pathways, including potential mediation effects.

Similar to LMM, data from the final five trials for each condition were used. The dependent variables were SoJA1, SoJA2, and SoA. Exogenous variables were change, fluctuation, extraversion, and attachment. The mediating variables were error and program-likeness. The model hypothesizes both direct and indirect effects of change and fluctuation on agency through error and program-likeness. Additionally, extraversion and attachment were posited to influence agency and program-likeness. The covariances between agency and individual traits were also incorporated to account for their interdependencies.

## Results

### Results of Linear Mixed-effects Model

Table 1: The results of the LLM

| Predictor | SoJA1 | | | | |
|---|---|---|---|---|---|
| | *β* | *SE* | *t-value* | *p-value* | |
| (Intercept) | 5.29 | 0.44 | 11.90 | < .001 | *** |
| Change | 0.65 | 0.29 | 2.24 | .027 | * |
| Fluctuation | 0.12 | 0.29 | 0.42 | .675 | |
| Error | -0.0068 | 0.019 | -0.36 | .718 | |
| Program-likeness | -0.18 | 0.072 | -2.46 | .015 | * |
| Change * Fluctuation | -0.089 | 0.41 | -0.22 | .830 | |
| **Predictor** | **SoJA2** | | | | |
| | *β* | *SE* | *t-value* | *p-value* | |
| (Intercept) | 3.96 | 0.45 | 8.86 | < .001 | *** |
| Change | 0.47 | 0.30 | 1.56 | .121 | |
| Fluctuation | 0.46 | 0.30 | 1.53 | .130 | |
| Error | 0.13 | 0.019 | 6.72 | < .001 | *** |
| Program-likeness | -0.16 | 0.073 | -2.15 | .033 | * |
| Change * Fluctuation | -0.89 | 0.43 | -2.09 | .039 | * |

*** $p < .001$, * $p < .05$

Table 1 shows the results of the LLM. The main findings for each dependent variable are as follows.

For SoJA1, the main effect of change was significant ($p = .027$, $\beta = 0.65$). This result indicates that the sense of joint agency increased when the proportion of the cursor movement reflecting the participant's input (α) increased linearly. In contrast, the main effect of fluctuation and the interaction between change and fluctuation were not significant, suggesting that the fluctuation of α had minimal impact on SoJA1. Additionally, the main effect of program-likeness was significant ($p = .015$, $\beta = -0.18$), indicating a tendency for SoJA1 to increase as participants perceived the partner as more human-like.

For SoJA2, the interaction between change and fluctuation was significant ($p = .038$, $\beta = -0.89$). This result suggests that the combined effects of linear increases and fluctuations in α influenced SoJA2. Similar to SoJA1, program-likeness has a significant negative effect on the ratings ($p = .033$, $\beta = -0.16$), reaffirming that perceiving the partner as more human-like leads to higher SoJA2. Furthermore, error showed a significant effect ($p < .001$, $\beta = 0.13$), indicating that larger errors (worse performance) were associated with increased SoJA2.

The results indicated that changes significantly enhanced SoJA1, whereas fluctuations showed no notable impact. For SoJA2, the interaction between the change and fluctuation influenced the ratings. Human-likeness consistently contributed positively to both SoJA1 and SoJA2, whereas performance errors positively affected SoJA2.

### Results of Path Analysis

The results of the path analysis summarized in Figure 3 reveal several key findings. Change had a significant positive effect on SoJA1 ($\beta = 0.133$, $p < .001$), indicating that a linear increase in α enhanced the sense of joint agency. However, the effect of change on SoJA2 was not significant ($\beta = 0.004$, $p = .913$), suggesting that the impact of change on joint agency depends on the question format.

In contrast, fluctuations showed no significant effects on SoJA1 and SoJA2. This result suggests that fluctuation in the α value had a minimal influence on participants' ratings of both joint agency.

Program-likeness showed a negative impact on both SoJA1 ($\beta = -0.27$, $p < .001$) and SoJA2 ($\beta = -0.24$, $p < .001$), suggesting that perceiving the partner as more human-like increased the sense of joint agency.

Error did not significantly affect SoJA1 but showed significant positive effects on SoJA2 ($\beta = 0.267$, $p < .001$). This finding indicates that worse performance tends to enhance SoJA2.

Individual traits such as extraversion and attachment also influenced the results. Extraversion positively affected the program-likeness ($\beta = 0.20$, $p < .001$), leading participants with higher extraversion to perceive the partner as more program-like. Conversely, attachment negatively impacted

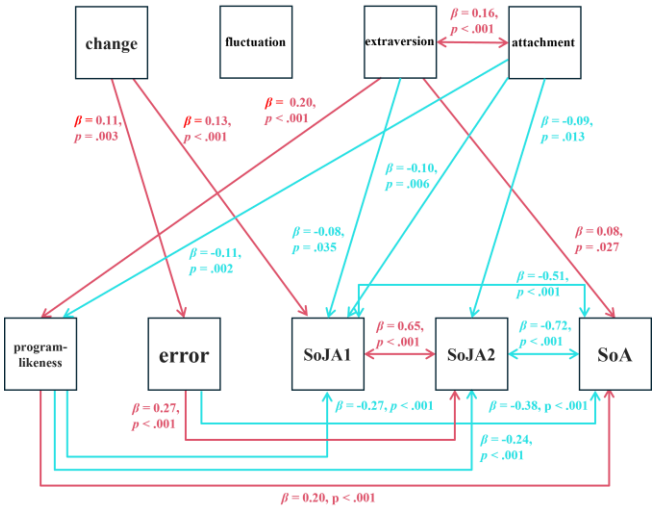


Figure 3: The results of the path analysis. Significant standardized coefficients and *p-values*. Positive paths are displayed in red, while negative paths are displayed in blue

program-likeness ($\beta$ = -0.11, $p$ = .002), suggesting that participants with higher attachment perceived the partner as more human-like. Both extraversion ($\beta$ = -0.077, $p$ = .035) and attachment ($\beta$ = -0.099, $p$ = .006) negatively influenced SoJA1, indicating that higher levels of these traits were associated with lower ratings of joint agency in this format. Attachment also negatively influenced SoJA2 ($\beta$ = -0.087, $p$ = .013), showing that participants with higher attachment tended to report lower levels of joint agency.

In summary, path analysis revealed that change enhanced SoJA1, whereas it did not affect SoJA2. Fluctuations had no significant effect on either measure of joint agency. Human-likeness positively influenced both SoJA1 and SoJA2, whereas poor performance increased SoJA2. Additionally, extraversion was linked to viewing the partner as more program-like and attachment associated with viewing the partner as more human-like. Both traits negatively influenced SoJA1 ratings, and attachment reduced SoJA2 ratings.

## Discussion

### Hypothesis Testing

We examined the effects of change and fluctuation on the sense of joint agency. Results of both the LLM and path analysis revealed that change had a significant effect on SoJA1, indicating that the linear change condition enhanced SoJA1 compared with the constant condition. However, fluctuations had no significant effect on either type of SoJA. The path analysis further showed that change did not affect the extent to which the partner was perceived as human-like. These results suggest that change directly enhances the sense of joint agency without being mediated by human-likeness. This finding contrasts with the hypothesis, which assumed mediation through human likeness. Similarly, fluctuations did not affect perception of human-likeness, contrary to the hypothesis.

The impact of perceived human-likeness on the sense of joint agency was then considered. LLM and path analysis consistently indicated that perceiving the partner as more human-like resulted in higher ratings for SoJA1 and SoJA2, reflecting an enhanced sense of joint agency. This outcome aligns with the hypothesis and reinforces prior research, suggesting that human-like appearances and intentionality attribution strengthen the sense of joint agency (Sahaï et al., 2023; Navare et al., 2024). This study uniquely quantified human-likeness using questionnaires and demonstrated its robust relationship with joint agency. These results indicate that the sense of joint agency is enhanced as long as partner is perceived as human-like, regardless of whether the partner is actually a person or not.

In summary, this study partially supports the initial hypothesis. While human-likeness was confirmed to enhance the sense of joint agency, the findings that change directly influenced joint agency without mediation through human-likeness and the lack of significant impact of fluctuation diverged from the initial hypothesis.

The direct influence of change on SoJA, bypassing human-likeness, may be explained by the participants' increased need to adjust to the partner's behavior under the linear change condition. Bolt et al. (2016) found that individuals who take on a greater role in adjusting their behavior during cooperative tasks tend to experience a stronger sense of joint agency. The present findings align with this observation, suggesting that the demands of behavioral adaptation under the change condition may have amplified participants' sense of joint agency.

### Influence of Individual Traits on SoJA

The results showed that extraversion and attachment negatively influenced the sense of joint agency, contrasting with a previous study's findings. Path analysis revealed that participants with lower extraversion and attachment scores tended to have higher SoJA1. Attachment also negatively influenced SoJA2. In contrast, Trần et al. (2024) reported that individuals with higher extraversion, agreeableness, and cognitive empathy are likelier to experience "united agency," a concept referring to a sense of unity during activities like music performance, dance, or team sports.

"United agency" is characterized by the feeling of acting "as one" with others, where the boundary between self and others' agency becomes blurred (Pacherie, 2012). In contrast, the sense of joint agency examined in this study refers to distributed control between co-actors, with the self and others' roles remaining distinct (Pacherie, 2012).

These conceptual differences between "united agency" and the sense of joint agency as defined in this study may account for the observed divergence in results. Furthermore, this study provides novel insights into the relationship between individual traits and sense of joint agency.

### Influence of Individual Traits on Human-likeness

In this study, participants with higher extraversion were more likely to perceive their partner as program-like, whereas those with higher attachment were more likely to perceive their partner as human-like.

Fujishima et al. (2005) described extraversion as comprising traits such as dominance, sociability, and attention seeking, whereas attachment was characterized by empathy, trust, and cooperation. These differences may explain the trends observed. Individuals with high extraversion may tend to dominate interactions, potentially viewing their partner as a controllable program. By contrast, individuals with stronger attachment tendencies may empathize with and respect their partners, perceiving them as more human-like.

These findings demonstrate the influence of individual traits on the perception of human-likeness, thus offering a novel contribution to the field.

### Influence of Task Performance on SoJA

The results showed that errors, defined as the deviation between the cursor trajectory and the circle, did not affect SoJA1 but significantly influenced SoJA2. This suggests that poor performance is associated with higher SoJA2 ratings.

The discrepancy between the two measures may be attributed to the differences in their susceptibility to bias. SoJA1, which focuses on whether the control is independent or shared, requires relatively objective judgment. In contrast, SoJA2 emphasizes whether the manipulation was performed by "me" or "us," incorporating more subjective elements. Prior research has shown that the sense of agency is strongly influenced by task performance, with successful trials enhancing agency and unsuccessful trials diminishing it (Sato & Yasuda, 2005; Wen, Yamashita, & Asama, 2015).

In this study, performance feedback was provided after participants rated their sense of agency, potentially affecting their impressions of cursor control. The subjective nature of SoJA2 may have increased susceptibility to bias. Participants might have attributed task failures not solely to themselves but also to themselves and their partners, thereby distributing the responsibility between the two.

The finding that poorer performance increases the sense of joint agency diverges from previous studies, such as the tapping task study by Loehr (2018), which demonstrated that better performance enhances the sense of joint agency. This discrepancy may stem from differences in the task design. In the present study, there was no explicit partner, making it challenging for the participants to separate their own contributions from those of their partners. This lack of distinction may have made participants more susceptible to performance-related biases.

These results provide novel insights highlighting the relationship between poor performance and heightened joint agency.

### Limitations and Future Directions

The factors of change and fluctuation did not influence human-likeness, failing to support the hypothesis. This result could be attributed to the possibility that the implemented change and fluctuation did not sufficiently capture the hypothesized concepts of "adaptation" or human-like "fluctuation." Alternatively, it is possible that "adaptation" and "fluctuation" do not significantly impact human-likeness. Designing experimental conditions that more directly represent "adaptation" and "fluctuation" could help clarify whether the lack of significant findings in this study was due to limitations in operationalizing these factors or their inherent inability to influence human-likeness perception.

In addition, although the required sample size was determined based on a power analysis for ANOVA, this approach may be insufficient for path analysis due to its greater complexity and the larger number of parameters included. Future studies should consider conducting power analyses tailored to structural equation modeling.

## Conclusion

This study investigated how differences in a partner's behavioral process influence the sense of joint agency, mediated by human-likeness. Participants completed a cursor-tracing task simulating collaboration, with the cursor movement combining their input with pre-recorded data. This study hypothesized that partners demonstrating adaptation and fluctuation would be perceived as more human-like, enhancing their sense of joint agency. A linear mixed-effects model and path analysis were used to evaluate both the direct and mediated effects.

The "change" factor, simulating adaptation by gradually increasing the proportion of participant input ($\alpha$), directly enhanced joint agency without mediation through human-likeness. In conclusion, the "fluctuation" factor, introducing trial-by-trial fluctuation in $\alpha$, showed no significant effects on either human-likeness or joint agency. Perceived human-likeness enhanced joint agency, suggesting that joint agency is heightened as long as the partner is perceived as human-like, regardless of their true nature. These findings partially support the hypothesis but contradict expectations regarding the roles of change and fluctuation in influencing human-likeness.

Unexpectedly, participants with higher extraversion tended to perceive their partners as more program-like, whereas those with higher attachment perceived them as more human-like. Participants with lower extraversion and attachment scores reported a higher sense of joint agency. Contrary to previous research, poor task performance was associated with a higher sense of joint agency.

In conclusion, the sense of joint agency is influenced by perceived human-likeness, extraversion, attachment and task performance. These findings provide valuable insights into the factors that shape the sense of joint agency.

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