Us and Them: Anticipated Imitation Between Groups

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Abstract

People's propensity to imitate others' actions is well documented. However, research on imitation remains mainly focused on dyadic social interactions, disregarding that we often interact with others as parts of larger groups. Extending sparse research on imitation beyond dyadic interactions, the current study investigated how anticipated imitation effects become modulated in social interactions between groups. Participants performed an anticipated imitation task in a virtual environment depicting four animated hands that were controlled by the participant, a virtual co-actor, and two virtual agents of an opposing dyad, respectively. Participants responded to symbolic stimuli by lifting their index or middle finger and performed the task either alone or together with their co-actor, while either one or both agent(s) of the opposing dyad imitated their responses. We found that participants' task accuracy was affected by group-level congruency relations between the two dyads: Acting together with another co-actor was facilitated when both vs. one agent(s) of the opposing dyad imitated participants' responses, while the opposite trend emerged when participants performed the task without their co-actor. A descriptively similar performance pattern in participants' response time data did not reach statistical significance. Explorative analysis showed that this performance pattern was moderated by participants' general response speed and was obscured by participants who responded relatively fast on the task. Our findings indicate that anticipated responses of multiple interaction partners can play a causal role in controlling one's own contributions to a social interaction and provide novel evidence that joint task representations encode actions on a group level.

Keywords: Joint action, Action representation, Anticipated imitation, Group interactions

1. Introduction

An extensive body of research shows that humans possess a marked tendency to imitate the behaviours of others, fulfilling crucial instrumental functions for social affiliation, observational learning, action prediction and interpersonal coordination (Heyes, 2011; Lakin et al., 2003; Wilson & Knoblich, 2005). Given its functional relevance, research on imitation has long served as a window into the cognitive representations and mechanisms that shape and support social interaction.

Prominent mechanistic explanations of our propensity to imitate the actions of others derive from ideomotor accounts of human action control (Brass & Heyes, 2005; Wohlschläger et al., 2003). These accounts build on the idea that actions are controlled by representations of their anticipated sensory outcomes, thus assuming a shared representational system for action and perception (Greenwald, 1970; Hommel, 2013; Hommel et al., 2001; Prinz, 1997; Shin et al., 2010). In the context of social interactions, a critical implication of ideomotor accounts is that actions performed by *other* people can directly affect the execution of one's *own* actions: As the actions performed by other people will most often resemble the sensory outcomes of our own actions, observing or anticipating others' actions is thought to activate corresponding action representations in the observer.

Ample empirical evidence for this assumption is provided by two related phenomena. First, a large body of research on *automatic imitation* demonstrates that action execution is facilitated by the concurrent observation of similar (i.e., congruent) and impaired by the concurrent observation of dissimilar (i.e., incongruent) actions performed by other agents (see Cracco et al., 2018 for a recent meta-analysis). These findings indicate that perceptual representations of actions triggered by *action observation* activate corresponding motor representations in the observer, facilitating or interfering with the execution of congruent or incongruent action plans respectively.

Second, research on *anticipated imitation* has provided converging evidence that not only external observation but also the *internal anticipation* of other people's actions can facilitate or interfere with the execution of congruent or incongruent action plans respectively (Müller, 2016; Pfister et al., 2013, 2017; Weller et al., 2019). In particular, these studies demonstrated that being predictively imitated by another agent facilitates performance of to-be-imitated motor responses compared to motor responses that are predictively followed by counter-imitative (i.e., incongruent) responses of another agent (see Pfister et al., 2025 for review). Resembling findings from response-effect compatibility studies (e.g., Ansorge, 2002; Keller & Koch, 2006; Kunde, 2001; Pfister & Kunde, 2013), these findings convincingly show that *anticipated* action outcomes — including predictable responses of other people (c.f., Kunde et al., 2018) — play a causal role in controlling one's actions, facilitating or interfering with motor plans that share compatible or incompatible features with its anticipated outcomes respectively.

1.1. From dyadic imitation to imitation of multiple agents

Most research on imitation is focussed on dyadic social interactions in which individuals observe or anticipate the actions of a single agent (see Fig. 1A). This focus, however, neglects the fact that many of the social interactions people take part in involve interactions with larger groups of people. E.g., teachers must monitor the behaviour of multiple students in parallel, soccer players must take the actions of multiple team mates and opponents into account to plan their next move, and conductors must orchestrate the actions of a whole ensemble of different musicians at once. Therefore, recent research efforts have started to extend research on dyadic imitation by investigating how observing or anticipating the actions of multiple agents influence individuals' action planning and control processes (see Cracco, 2025 for review).

Investigating how automatic imitation effects scale with the number of observed actions, Cracco and colleagues (2015) showed that observing *identical* actions performed by more than one agent produces stronger automatic imitation effects, which were found to increase asymptotically with the number observed actions (Cracco & Brass, 2018b), ceiling at group sizes involving up to ten agents (Cracco et al., 2022). Moreover, studies investigating effects of observing *different* actions of multiple agents have shown that concurrently observed actions can be reliably decoded from brain activity in the observer's motor system (Cracco et al., 2019), elicit concurrent imitative response tendencies (Cracco & Brass, 2018a), and activate conflicting action representations in the observer (Cracco et al., 2019, 2021). Taken together, these studies indicate that people represent the actions of multiple observed agents simultaneously in their motor system and show that basic action planning processes can be influenced by the observation of multiple agents at once.

In contrast to the growing body of studies investigating automatic imitation of multiple agents, less is known about the behavioural effects of being imitated by more than one agent. An initial investigation of this topic by Galang et al. (2024) showed no evidence that anticipated imitation effects are influenced by the number of imitators with recent findings by Neszmélyi and Pfister (2024) showing similar results.

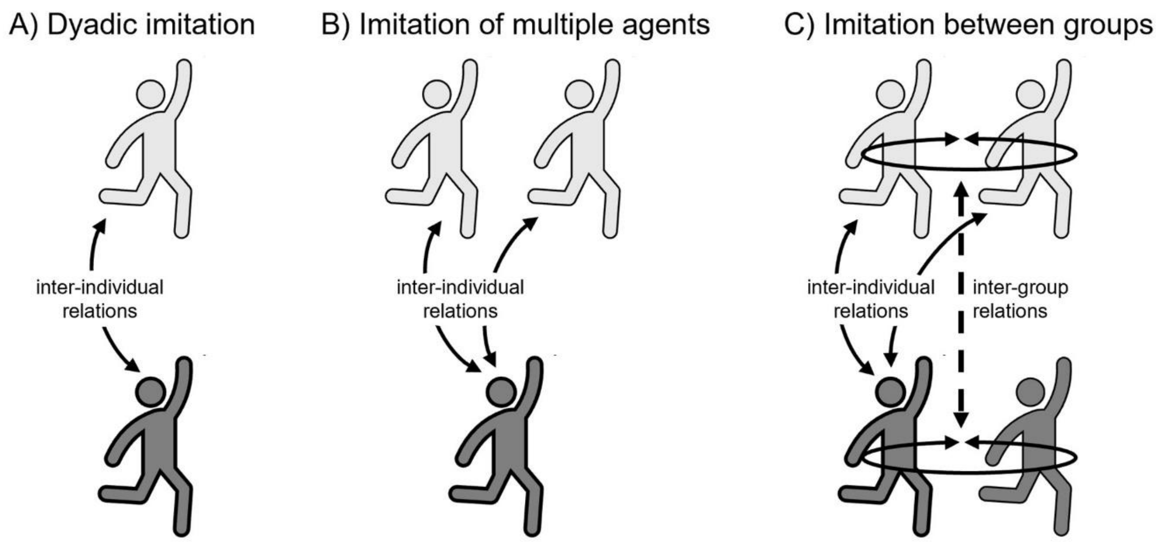


Fig. 1. Illustration of different congruency relations between own and others' actions in social interactions between A) two individual agents, B) an individual agent and multiple other agents, and C) two opposing groups of jointly acting individuals. Solid arrows represent inter-individual relations between actions of single agents. The dotted arrow represents inter-group relations between actions performed by one group and those performed by the other.

1.2.From imitation of multiple agents to imitation between groups

Extending research on dyadic imitation, the research reviewed in the preceding section focussed on situations in which *individuals* observe or anticipate the actions of multiple agents (see Fig. 1B). However, when multiple people come together, we may encounter a group of people not just as individuals, but often as part of a group ourselves. I.e., we often observe or anticipate the actions *of* multiple agents, while interacting *with* other agents at the same time (see Fig. 1C). E.g., as a couple in a ballroom dance class, we may try to copy the joint moves performed by another dance couple; or as part of a tennis double, we may anticipate the next moves of our two opponents, while coordinating the running paths on our half of the pitch.

Thus, an interesting question to ask is how being part of a group may shape effects of observing or anticipating another group of agents. As a caveat to this question, one may wonder why observing or anticipating the actions of a group of people should have different effects when acting as part of a group oneself compared to when acting merely as a single individual. One hypothesis could be that effects of action observation or anticipation are solely driven by *inter-individual relations* between the actions performed by oneself and the actions performed by all other individuals in the interactive scenario (c.f., Fig. 1C, solid arrows). As such, the two-groups scenario would not be much different than the scenario in which an individual observes or anticipates the actions of multiple other agents, and imitation effects may simply scale with the total number of agents in the scene.

Crucially though, research findings in the domain of *joint action* suggest that individuals performing a task together with other co-actors (i.e., as part of a group) form action representations that integrate their co-actors' actions into *joint task representations* that encode relations between one's own and one's co-actors' actions emerging at the level of their group-level performance (sometimes referred to as "we-representations"; c.f., Kourtis et al., 2019; Marschner et al., 2024; Sacheli et al., 2018; Sinigaglia & Butterfill, 2022). Importantly, these representational peculiarities of joint as compared to individual action, suggest an alternative hypothesis about how effects of action observation and anticipation might be modulated in social interactions between groups (c.f., McEllin et al., 2018; Milward & Sebanz, 2016). When people perform a task together with other co-actors while observing or anticipating the actions of another group of jointly acting individuals, not only *inter-individual relations* between own and others' actions may affect people's action planning and control processes but also *inter-group relations* that emerge between the group-level performance of one group relative to that of the other group (see Fig. 1C, dashed arrow).

Testing this possibility, Tsai et al. (2011) conducted an experiment in which participants performed a task alongside a confederate co-actor in which they imitated the movements of two hand stimuli depicted on a computer monitor in front of them. In different conditions, participants performed the task either without (individual response) or together with the confederate (joint response), in response to observing either one or both hands moving on screen. Interestingly, results showed that response times were fastest when the number of movements observed on screen matched the number of imitative responses performed by participants and their confederate respectively. That is, *individual* responses were faster when imitating movements of one vs. two hand(s), while *joint* responses were faster when imitating movements of two vs. one hand(s) (see Essa et al., 2019 and Ramenzoni et al., 2014 for similar findings). Interestingly, this effect emerged only if the observed hand stimuli were displayed as belonging to another dyad but not when displayed as belonging to a single individual. This finding shows that in interactions between groups, imitation effects are indeed shaped by inter-group rather than inter-individual action relations, which affects how observed actions are mapped to actions performed in response to them. Crucially, this finding seems to indicate that actions performed together with others are coded qualitatively different than actions performed alone, namely in relation to group-level rather than individual-level performance.

1.3.The present study

The findings by Tsai et al., (2011) provide initial evidence that acting as part of a group changes how we process and respond to the actions we observe in others. But does this justify the conclusion that actions performed together with others are planned and represented qualitatively different then actions performed alone? One objection could be that the group-level congruency effects found by Tsai et al. (2011) are caused by *action observation*, i.e., by the external perception of individual or joint actions, priming the subsequent execution of individual or joint action plans respectively. As such, they may show that individual and joint action plans become *exogenously* activated by *observing* individual or joint actions in others. Yet, they can provide only limited insights into the *endogenous* mechanisms that would drive the activation of individual or joint action plans in a goal-directed, self-initiated way.

Crucially, the central hypotheses of ideomotor theories is that goal-directed actions are initiated and controlled by *anticipations* of their perceivable outcomes — that is, by future rather than currently perceived events (Kunde, 2001a). Applied to social interactions between groups, tapping into the anticipatory nature of human action planning would thus require to study effects of *anticipating* rather than *observing* the actions of another group of agents. This was precisely the aim of present study.

To this end, we converted the experimental design by Tsai et al. (2011) to an anticipated imitation task. Rather than responding to observed actions of one or two agents either alone or together with another co-actor, in our experiment, participants performed a stimulus-response task either alone or together with another agent, while their responses where predictively imitated by either one or two agents of an opposing dyad. Fig. 2 provides an overview our experimental setup and design.

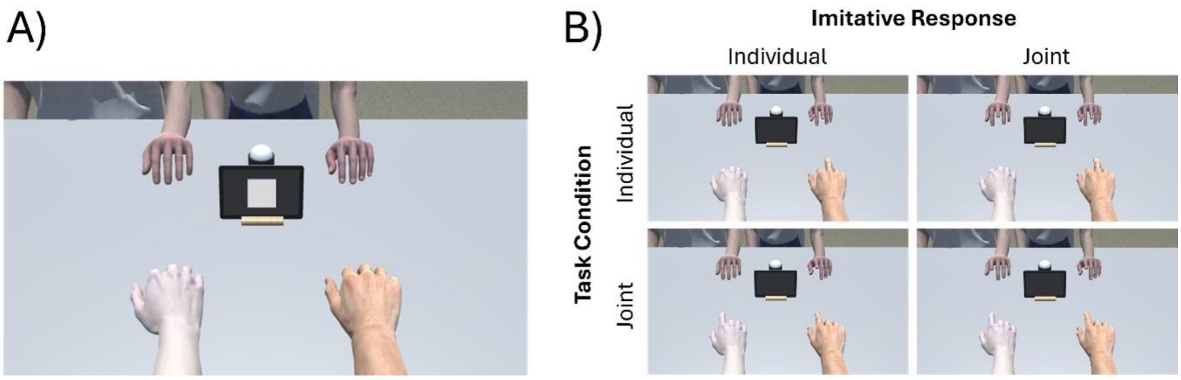
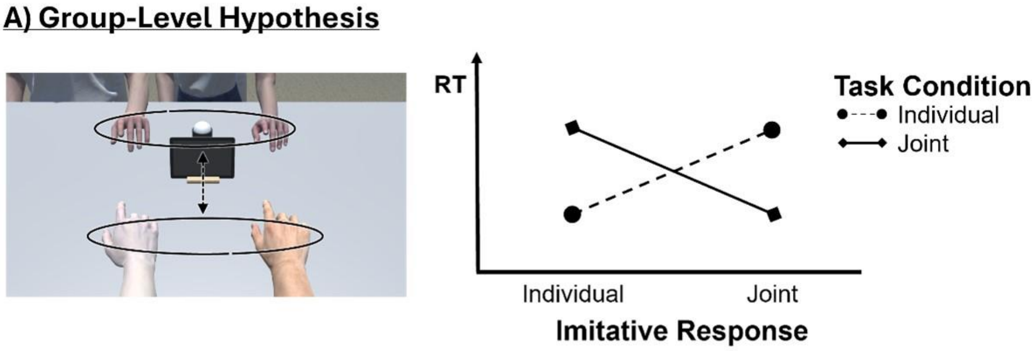


Fig. 2. Experimental setup and design. A) Participants performed a two-alternative forced choice task in a virtual environment depicting four animated avatar hands. Participants task was to lift the index or middle finger of their right hand in response to shape stimuli (square or circle) appearing on screen. One of the two hands displayed in the lower half of the scene was introduced as representing participants' own hand which always mirrored participants' finger lift responses as they performed them. The hand next to the participant's hand was introduced as belonging to a virtual partner performing the task alongside participants. The two hands displayed above participant's and their partner's hand were introduced as belonging to two virtual agents observing participant's and their partner's finger lift responses with the aim to imitate them. B) In different blocks, participants performed the task either without (individual task condition) or together with their virtual partner (joint Task condition), while either one (individual imitation) or both (joint imitation) of the opposing agents imitated participants' finger lift responses.

Under the assumption that anticipated responses of other people get employed to initiate and control one's own contribution to a social interaction (Kunde et al., 2018), our experimental setup allows us to test whether actions performed together with others are indeed planned and represented differently than actions performed alone. If actions performed together with others are planned and represented in relation to group- rather than individual-level performance (group-level hypothesis), performing an action *together* with another co-actor (joint action) should be facilitated by anticipating an imitative response by another dyad of jointly acting agents (joint imitation) but be impaired by anticipating an imitative response by a single member of another dyad (individual imitation). At the same time, performing an action *without* another co-actor (individual action) should instead be facilitated by anticipating an imitative response by a single member of another dyad (individual imitation) but be impaired by anticipating an imitative response by another dyad of jointly acting agents (joint imitation). In contrast, if actions performed together with others remain represented in relation to one's individual-level performance alone (individual-level hypothesis), facilitatory effects of anticipating imitative responses by other agents should be expected to simply scale with the number of imitative responses performed by all other agents. That is, performing an action may benefit from performing it together with another co-actor vs. alone and from being imitated by two vs. one member of another group. Fig. 3 illustrates the predictions of the group-level and individual-level hypothesis respectively.



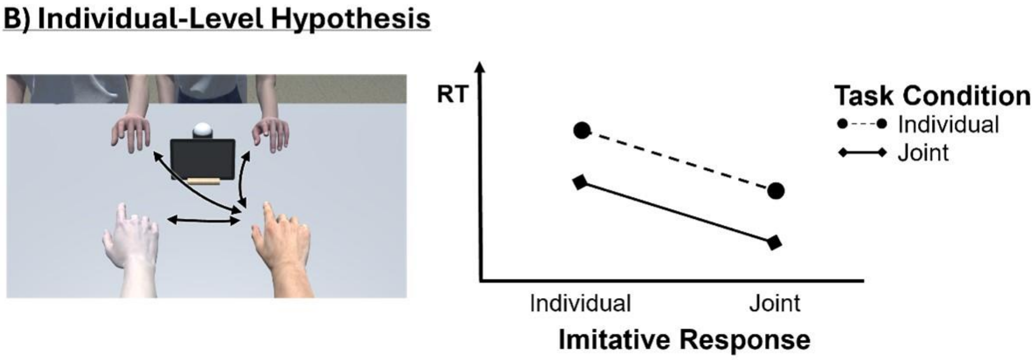


Fig. 3. Contrasting hypothesis and resulting predictions for the current study. A) According to the group-level hypothesis, actions performed together with others are represented in relation to group-level performance (illustrated by the two ellipses). Acting together with another person (Joint Action) should then be facilitated by anticipated imitation of another dyad (Joint Imitation), while acting alone (Individual Action) should be facilitated by anticipated imitation of another individual agent (Individual Imitation). Participants' task performance should thus be driven by numerical congruency between the actions performed by their dyad and the actions performed by the imitating dyad, i.e., by congruency relations between groups rather than between individuals (illustrated by the dashed arrow). B) According to the individual-level hypothesis, actions performed together with others remain represented in relation to individual-level performance. Task performance should then be expected to scale with the number of imitative responses by all other agents in the interactive scene, i.e., by additive effects of congruency relations between individuals (illustrated by the solid arrows). *Note:* RT = response time as a measure of task performance (lower values indicate better performance).

2. Methods

2.1.Participants

In total, $N = 250$ participants took part in the experiment. The sample size was determined based on an a priori power analysis and pragmatic concerns regarding resource constrains. We wanted to ensure that our study would be sufficiently powered to detect a within-subjects interaction effect of size $\eta_p^2 = .03$ in a 2 x 2 repeated measures ANOVA with 80% power at an alpha level of .05. The effect size estimate was based on a series of pilot studies. To calculate the required sample size to find such an effect, we treated the two-way interaction effect as a paired-sample difference of difference scores between factor levels, transforming our effect size estimate of η_p^2 = .03 to dz ~ 0.18 in a paired samples t-test (c.f., Langenberg et al., 2023). Conducting an a priori power analysis with these input parameters in G*Power (ref) we calculated a required sample size of N = 245. Assuming that we would need to remove a number of participants from our sample due to our preregistered exclusion criteria (see below), we eventually decided to collect data from N = 250 participants. From the final sample 19 participants were eventually excluded which led to a final sample size of N = 231 participants (mean age = 30.0 years, standard deviation = 5.9 years; 42 % female, 58 % male)

Participants were recruited on the online research platform Prolific (prolific.com). All participants were right-handed, had normal or corrected-to-normal vision, resided in the UK and were fluent in English. All participants gave their informed consent before participation and were compensated with 3 GBP for completing the experiment in approximately 20 minutes. Ethical approval for the study was granted by the Psychology Ethics Committee of Humboldt University Berlin.

2.2. Apparatus and stimuli

Participants performed the experiment online in a browser on their own personal computer. Experiment files and data were stored on a JATOS server (Just Another Tool For Online Studies, Lange et al., 2015) hosted by Humboldt University Berlin. The experimental task was built in Unity and was controlled by a custom made C# script. The task was set in a virtual 3D environment depicting four animated avatar hands resting on the surface of a white table (see Fig. 2A). One of the two avatar hands in the lower part of the scene was introduced as representing participant's own hand that would mirror their responses in the experimental task. The other hand in the lower part of the scene was introduced as belonging to a virtual partner that would perform the experimental task together with the participant. The two avatar hands at the top of the scene were introduced as belonging to two virtual agents that would observe the participant's and their partner's finger lift responses in order to imitate them. Participants responded by operating the "N" and the "M" key on their keyboard with the index and the middle finger of their right hand respectively. Imperative stimuli instructing participants' responses were a circle and a square displayed in grey. Shape stimuli, trial-level instruction and feedback prompts were presented on the depiction of a small tablet monitor displayed in the center of the scene. All avatar models in the scene were purchased from the Unity Asset Store. Movement animations of the avatar hands were self-created with UMotion Pro, a Unity package for animating rigged avatar models. The duration of the movement animations (from resting state to the respective finger being up) was set to five frames, corresponding to ~ 165 ms assuming a display rate of 30 frames per seconds.

2.3. Procedure and design

Participants were instructed to respond to the presentation of two shape stimuli by lifting the index or middle finger of their right hand from their response keys respectively. The experiment started with a familiarization phase in which participants first trained the task alone with only their avatar hand being displayed in the scene, followed by a series of training trials performed together with the virtual co-actor in which only participants' avatar hand and that of their virtual co-actor were displayed[1]. After performing eight successful training trials in each of these trial series, participants proceeded to the main part of the experiment. Here, participants were informed that they would perform the task in different blocks either with (Joint Action) or without their virtual partner (Individual Action) and that either one (Individual Imitation) or both (Joint Imitation) of the opposing avatars would imitate their finger lift responses.

[1] The trial timeline in the familiarization phase corresponds to that described for the main part of the experiment, just without an imitative response of the opposing avatars, which were not yet visible in this phase of the experiment.

The trial timeline for the main part of the experiment is illustrated in Fig. 4. Each trial started with a "Hold" prompt displayed on screen, instructing participants to hold down both of their response keys. As soon as participants complied, the "Hold" prompt disappeared after 500 ms followed by a fixation cross presented for a duration of 1000 ms. If participants released one of their keys during this period, an error message ("Too early") was displayed for 1500 ms and the trial started all over. Otherwise, the fixation cross was followed by the presentation of one of the shape stimuli, displayed until participant's response or until the end of a maximum response window of 1500 ms. As soon as participants lifted one of their fingers from their response keys within this window, a corresponding finger lift animation of their avatar hand was triggered. In Individual Action blocks the avatar hand of the virtual partner remained in resting position (all fingers down) throughout the whole block. In Joint Action blocks, participants' responses also triggered a finger lift animation of their partner's avatar hand which was played after a jittered delay ranging between 0 and 20 ms. If triggered, the partner's avatar hand always lifted the correct finger.

If participants responded correctly, either one (in Individual Imitation blocks) or both (in Joint Imitation blocks) of the opposing avatars lifted the same finger as participants. The respective animations were triggered after an interval ranging between 200 and 220 ms. The

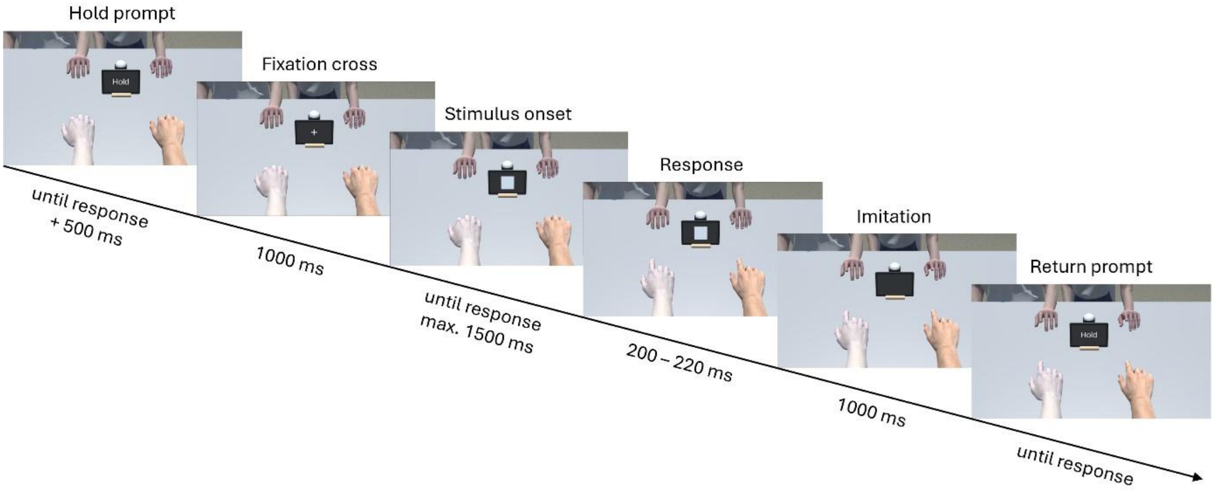


Fig. 4. Trial timeline for the main part of the experiment. The example shows a trial in which participants responded to the shape stimuli together with their virtual co-actor (joint action) and where imitated by both members of the opposing dyad (joint imitation).

final outcome, i.e., two to four hands lifting the same finger, was displayed for at least 1000 ms after which another "Hold" prompt instructed participants to press and hold down both of their keys again. As soon as participants complied, their avatar hand lowered the respective finger again. Depending on the current block, the partner's avatar hand followed to lower their finger directly after and, after another delay ranging between 200 and 220 ms, either one or both of the two opposing avatars did so as well. The next trial started after an inter trial interval of 500 ms in which all four hands were displayed in their starting position again.

If participants lifted the wrong finger, an error message was displayed and a signaling lamp in the scene turned red for 1500 ms. Participants were informed that the red lamp would signal the opposing avatars to withhold their imitative response. The error message was followed by a "Hold" prompt, instructing participants to return to the starting position as described above. If participants failed to respond within the response window, their own and their partner's avatar hand, as well as those of the two opposing avatars remained in their resting position and a feedback message ("too slow!") was displayed for 1500 ms, followed by the "Hold" prompt as described before.

To ensure that participants paid attention to the imitative responses of the opposing avatars, we implemented occasional catch trials, in which the imitating avatar(s) lifted their finger twice. If participants noticed this behavior, they had to release their remaining finger from their keyboard within a response window of 1500 ms. If participants failed to respond as described, a feedback message was displayed for 5000 ms, reminding participants what to do when noticing a double finger lift of the opposing avatar(s). The feedback message was then followed by the "Hold" prompt and the related procedure as described above.

The study thus had a 2 x 2 fully within-subjects factorial design with Task Condition (Individual Action vs. Joint Action) and Imitative Response (Individual Imitation vs. Joint Imitation) as within-subjects factors. Participants performed 40 trials in each of the four blocks corresponding to the four experimental conditions resulting from our factorial design. Each block started with an instruction text, announcing whether participants were going to perform the block with or without their virtual partner and whether one or both opposing avatars were going to imitate their responses. Each block started with a series of training trials to familiarize participants with the structure of the block. The actual block started after two successful training trials. In blocks where only one of the opposing avatars would perform an imitative response, the side of the imitating avatar (i.e., the left or the right one) changed after the first half of the block (which was announced and preceded by a new series of training trials)[2]. Stimuli presentation (square vs. circle) was pseudo-randomized to account for balanced numbers of both stimuli in each half of each block. Four of the 40 test trials in each block were catch trials, two randomly allocated to the first and two randomly allocated to the second half of each block (the required response on catch trials was counterbalanced in both halves of each block). Stimulus-response mappings were counterbalanced between participants. Furthermore, we counterbalanced the position of participants' avatar hand within the scene, which was displayed either on the lower left or the lower right half of the scene. We also counterbalanced the position of the avatar imitating participants responses in the first and second half of the Individual Imitation blocks. Finally, block order was counterbalanced between participants using a balanced Latin square design with four possible block orders[3].

A demonstration of the experimental task and procedure can be accessed through the following link: https://jatos.psychologie.hu-berlin.de/publix/UTRIz5ZcSRX.

[2] This was done to control for possible spatial compatibility effects while ensuring predictability of the imitative responses.

[3] The four possible block orders were A) [Individual Action | Individual Imitation], [Individual Action | Joint Imitation], [Joint Action | Joint Imitation], [Joint Action | Individual Imitation], B) [Individual Action | Joint Imitation], [Joint Action | Individual Imitation], [Individual Action | Individual Imitation], [Joint Action | Joint Imitation], C) [Joint Action | Individual Imitation], [Joint Action | Joint Imitation], [Individual Action | Joint Imitation], [Individual Action | Individual Imitation], D) [Joint Action | Joint Imitation], [Individual Action | Individual Imitation], [Joint Action | Individual Imitation], [Individual Action | Joint Imitation].

2.4. Analysis plan

Training trials were not included in our analysis. From the 40 test trials in each block we excluded trials with response omissions and trials in which participants responded by releasing both of their keys at once (1.1 % of all trials). From the remaining trials, we excluded trials with a response time (RT) that was more than 3 standard deviations away from participants' individual mean RT aggregated across all trials in the experiment (1.4 % of remaining trials). On the participant level, we excluded participants who failed to respond to all of the catch trials in at least one of the four blocks (affecting 19 participants) and those with an overall response error rate (ER) above 20% (affecting no further participant). For the remaining sample, participants' RT and ER were aggregated and analyzed by means of separate 2 x 2 repeated-measures ANOVAs with Task Condition (Joint Action vs. Individual Action) and Imitative Response (Individual Imitation vs. Joint Imitation) as within-subjects factors. Data was preprocessed and analyzed in R. ANOVAs were run with the *afex* package using type three sums of squares. Significant interactions were followed up by simple main effect analysis using the *emmeans* package. For all inference statistical analysis, alpha level was set to .05 and was Bonferroni-corrected in case of multiple comparisons.

2.5.Transparency and openness

Data collection happened in March 2025. Raw data and analysis scripts are accessible in an Open Science Framework project repository accessible under https://osf.io/jpxqr/overview?view_only=f80423ec981f4958a97abed65106745d. Directed hypotheses, study design, sampling and analysis plan were preregistered in the Open Science Framework. The preregistration can be accessed online under https://osf.io/sf8ru/?view_only=bdd178c8ce3841299064a1927c8f5c0b. Any deviations from the preregistration are mentioned explicitly and marked as explorative analysis.

3. Results

3.1. Pre-registered analysis

The results of the preregistered analysis are displayed in Fig. 5.

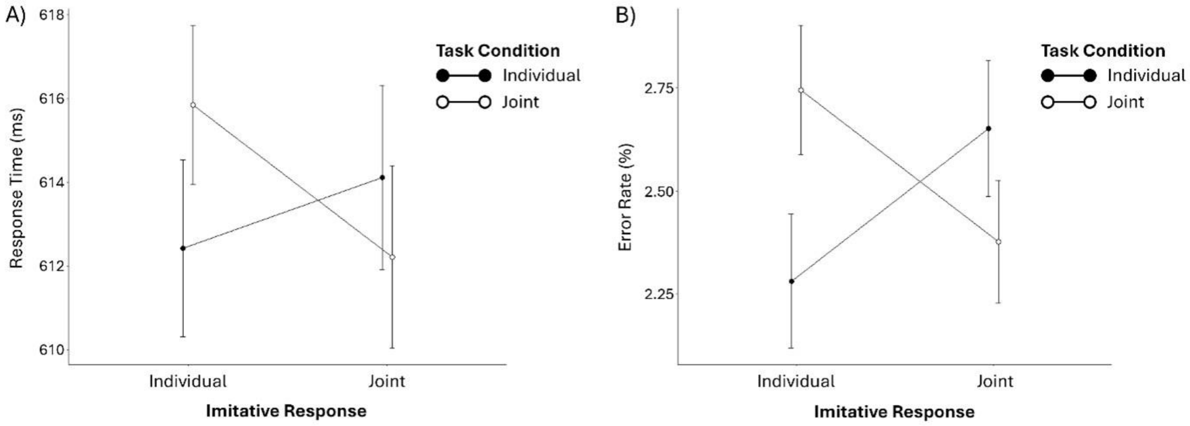


Fig. 5. A) Mean response time and B) mean error rate across participants as a function of Task Condition (Individual Action vs. Joint Action) and Imitative Response (Individual Imitation vs. Joint Imitation). Error bars represent standard error of the mean corrected for within-subjects designs.

The RT analysis revealed no statistically significant effects. The main effects of Task Condition and Imitative Response were non-significant (both $F < 1$). Crucially, the predicted interaction between Task Condition and Imitative Response also did not reach significance, $F(1, 234) = 1.43$, $p = .23$, $\eta^2 = .006$. At least descriptively though, participants responded slightly faster in Joint Action trials when imitated by both members of the opposing dyad (Joint Action | Joint Imitation: $M = 612$ ms, 95% CI [596, 628]) compared to when imitated by one member (Joint Action| Individual Imitation: $M = 616$ ms, 95% CI [599, 632]), while the reverse trend was observed in Individual Action trials (Individual Action | Joint Imitation: $M = 614$ ms, 95% CI [597, 631] vs. Individual Action | Individual Imitation: $M = 612$ ms, 95% CI [596, 629]).

The ER analysis showed no significant main effects of Task Condition or Imitative Response (both $F < 1$). Crucially though, the interaction between both factors reached significance, $F(1,234) = 4.68$, $p = .032$, $\eta_p^2 = .020$. Examining Fig. 5B, the interaction was driven by fewer response errors in Joint Action trials when participants were imitated by both members of the opposing dyad ($M = 2.38$ %, 95 % CI [1.97, 2.78]) compared to when being imitated by a single member (M = 2.74 %, 95 % CI [2.33, 3.15]), with the opposite pattern observed for Individual Action trials (Individual Action | Joint Imitation: M = 2.65 %, 95 % CI [2.20, 3.10] vs. Individual Action | Individual Imitation: M = 2.28%, 95 % CI [1.87, 2.69]). Yet, follow-up tests of simple main effects did not reach significance: Main effect of Imitative Response on Joint Action trials, $t(234) = -1.56$, $p_{corrected} = .24$; main effect of Imitative Response on Individual Action trials, $t(234) = 1.70$, $p_{corrected} = .18$.

3.2. Explorative analysis

Our preregistered analysis showed a performance pattern that partially aligns with the predictions of the group-level hypothesis. While a group-level congruency effect was evident for participants' error rates, descriptive differences in response times — although in line with the group-level hypothesis — did not reach statistical significance. Based on these initial findings, we decided to run a follow-up analysis, exploring possible moderators of performance differences between our experimental conditions. To this end, we first combined participants RTs and ERs into inverse efficiency scores (IES = RT / [1 - ER]; Townsend & Ashby, 1978) to get a combined measure of participants' task performance[4]. We then performed a median split of our sample based on participants' overall mean response time in the task. This allowed us to assess whether participants overall response speed could have moderated the group-level congruency effect indicated by our preregistered analysis. Analysing overall response speed as a possible moderator was motivated by the idea that participants who performed the task relatively fast may have selected their responses primarily in a stimulus-based rather than an effect-based action control mode (c.f., Waszak et al., 2005), i.e., by selecting their responses merely in compliance with the instructed stimulus-response mapping but without necessarily anticipating their distal effects in the environment (e.g., imitative responses performed by the

[4] Analyzing IES as a single measure of task performance is justified in the current study as error rates were relatively low while the converging patterns for error rates and response times provide no indications for a speed-accuracy trade off (Bruyer & Brysbeart, 2011).

avatar hands). As previous research findings have shown that compatibility effects between actions and their resulting consequences require an effect-based action control mode (Pfister et al., 2010; Zwosta et al., 2013), possible interactions between Task Condition and Imitative Response could thus have been overshadowed by participants who performed the task in a stimulus-based action control mode instead.

To test this post-hoc hypothesis, we thus analysed participants' IES by means of a 2 (Task Condition: Individual Action vs. Joint Action) x 2 (Imitative Response: Individual Imitation vs. Joint Imitation) x 2 (RT Group: Fast Responder vs. Slow Responder) mixed ANOVA with Task Condition and Imitative Response as a within- and RT Group as a between-subjects factor. The results are depicted in Fig. 6.

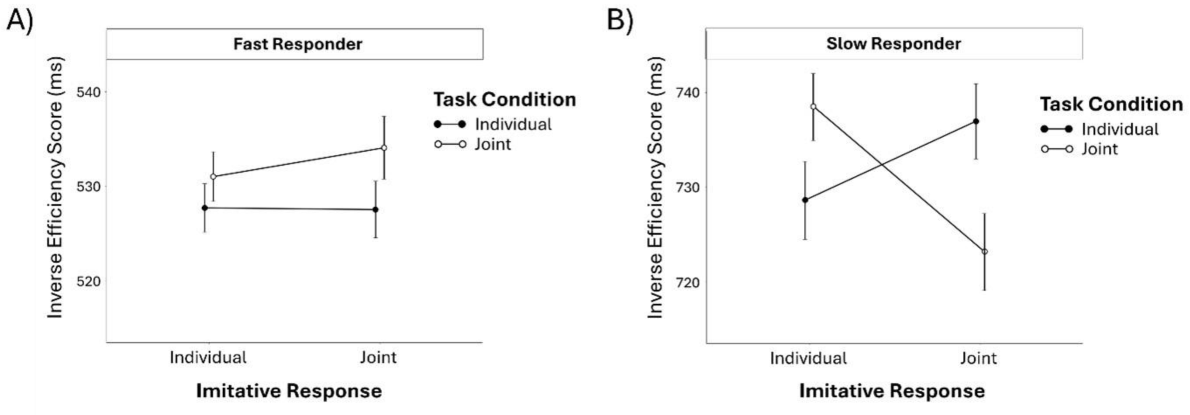


Fig. 6. Inverse efficiency scores as a function of Task Condition and Imitative Response plotted separately for A) fast responder and B) slow responder. Error bars represent standard error of the mean corrected for within-subjects designs.

Not surprisingly, the analysis showed a main effect of RT Group, $F(1,233) = 323.5$, $p < .001$, $\eta_p^2 = .581$. The two-way interaction between Task Condition and Imitative Response approached but did not reach statistical significance, $F(1,233) = 3.81$, $p = .052$, $\eta_p^2 = .016$. Crucially though, the analysis showed that this interaction was moderated by participants' overall response speed, as indicated by a significant three-way interaction between Task Condition, Imitative Response and RT Group, $F(1,233) = 6.61$, $p = .011$, $\eta_p^2 = .028$. No other effects were significant (see Appendix for the detailed result table). To follow-up on the three-way interaction, we analysed IES in each RT Group separately by means of two separate 2

(Task Condition) x 2 (Imitative Response) repeated-measures ANOVAs. Main effects of Task Condition and Imitative Response were non-significant in both analysis (see Appendix for the detailed result tables). Yet, contrasting both analysis showed that the two-way interaction between Task Condition and Imitative response was significant in the slow responder group, $F(1,116) = 7.21$, $p_{\text{corrected}} = .016$, $\eta_p^2 = .059$, while it was non-significant in the fast responder group ($F < 1$). Following up on the interaction between Task Condition and Imitative Response in the slow responder group showed that the interaction was driven by lower IES (i.e., better performance) in Joint Action trials when participants were imitated by both vs. one member(s) of the opposing dyad (Joint Action | Joint Imitation: $M = 723$ ms, 95 % CI [704, 743] vs. Joint Action | Individual Imitation: $M = 738$ ms, 95 % CI [718, 759]; $t(116) = 2.77$, $p_{\text{corrected}} = .013$), while the opposite trend emerged on Individual Action trials (Individual Action | Joint Imitation: $M = 737$ ms, 95 % CI [715, 759] vs. Individual Action | Individual Imitation: $M = 729$ ms, 95 % CI [707, 750]; $t(116) = -1.39$, $p_{\text{corrected}} = .33$).

4. Discussion

The present study assessed how being imitated by one (individual imitation) or two member(s) of an opposing dyad (joint imitation) affects to-be-imitated responses that are performed without (individual action) or together with another co-actor (joint action). Under the assumption that anticipated actions of other agents get employed to initiate and control one's own contributions to a social interaction (c.f., Kunde et al., 2018), the current study allowed us to test two opposing hypotheses about the structure and content of action representations guiding action performance in joint task settings. If actions performed together with others (i.e., joint action) are guided by task representations encoding group- rather than individual level performance (group-level hypothesis), task performance in the current study should be affected by congruency relations between the interacting groups: Joint action should be facilitated by anticipating joint vs. individual imitation, while individual action should be facilitated by anticipating individual vs. joint imitation. In contrast, if actions performed together with others are guided by task representations that remain centred on individual-level performance (individual-level hypothesis), task performance in the current study should be affected by congruency relations between individual agents: Task performance should increase the more agents mimic participants' individual responses.

Providing partial support for the group-level hypothesis, our findings showed that imitative responses of two vs. one member(s) of another dyad affected the accuracy of to-be-imitated responses in opposite ways, depending on them being performed with or without another co-actor. In other words, we found evidence that participants' response accuracy was driven by congruency relations between groups rather than individuals: Not the total number of anticipated responses by all individual agents in the scene, but congruency between the number of actions performed by participants' own group (i.e., "us") and the number of anticipated responses performed by the opposing group (i.e., "them") affected how accurate participants' performed the task. However, limiting the conclusiveness of our preregistered analysis, evidence for a group-level congruency effect was restricted to analysis of participants response accuracy, while analysis of participants response times — although showing a trend in the same direction — revealed no statistically significant effects.

Interestingly though, results of our explorative analysis suggest that significant performance differences between our experimental conditions were partially obscured by a subset of participants who responded relatively fast on the task compared to others. Our explorative analysis showed that the group-level congruency effect on task performance was moderated by participants' overall response speed: Those participants who responded relatively slow on the task but not those who responded relatively fast were affected by congruency relations between groups and showed opposing effects of being imitated by both vs. one member of the opposing dyad depending on whether they performed the task with or without their co-actor. In contrast, participants who responded relatively fast on the task showed no indications of being affected by imitative responses of other agents in the scene.

A possible explanation for this limiting factor in our results could be that the fast responding participants performed the task primarily in a stimulus-based rather than an effect-based action control mode, i.e., by selecting their responses simply in compliance with the instructed stimulus-response mapping but not with the aim to trigger imitative responses in the other agents (c.f., Herwig et al., 2007; Waszak et al., 2005). Previous research has shown that response selection is generally faster in stimulus- compared to effect-based action control modes (e.g., Keller et al., 2006; Waszak et al., 2005) and that congruency effects between actions and their outcomes depend on task instructions that foster effect-based rather than stimulus-based action control modes (Pfister et al., 2010; Zwosta et al., 2013). Indeed, task instructions in the current study focussed on participants' primary task to lift their index or middle finger in response to shape stimuli appearing on screen but made it less explicit that participants should do so in order to trigger an imitative response in the other agents. This might have led many participants to zoom in on their primary task to select responses in reaction to the task-relevant stimuli without integrating the responses of the other agents in the scene in to their own representation of the task.

The findings of the present study bear several indications. First, our findings inform research investigating how the behavioural changes we evoke in other people, i.e., the *social* consequences of our actions, get integrated into our own action planning and control processes. Previous research on so called *sociomotor action control* (Kunde et al., 2018) has shown that people access their own contributions to a social interaction by anticipating the behavioural responses they evoke in their interaction partners. Whereas demonstrations of this principle remained limited to dyadic interactions so far (for exemptions see Galang et al., 2024; Neszmélyi & Pfister, 2024), our findings indicate that people can use anticipated actions of *multiple* other agents to initiate and control their own contributions to a social interaction.

However, our findings also point to limitations in how readily people integrate behavioural responses evoked in others into their own action planning and control processes. The finding that only some but not all participants were affected by imitative responses of the other agents in the scene indicates that integrating predictable actions of others into representations of one's own actions is not an automatic process but seems to be dependent situational factors that may comprise people's current task construal or their dominant mode of action control. Future research on action control in social interaction should thus assess the conditions and enabling factors that make people more or less pronounced to represent their contributions to a social interaction in terms of the responses they evoke in others in a more systemic way (see Kunde et al., 2018 for a summary of initial findings).

Second and central to the aim of the present study, our findings inform research on the content and structure of joint task representations. The finding that participants' task performance was driven by congruency relations between groups indicates that participants formed task representations encoding group-level performance (i.e., "*WE* both lift our index finger") rather than individual level performance alone (i.e., "*I* lift my index finger"). As such, anticipating an imitative response by both members of the other group (i.e., "they will both lift their index finger") could prime access to the joint task representation of lifting one's finger together with one's co-actor, while anticipating an imitative response by only one member of the other group (i.e., "one of them will lift their index finger") could interfere with the joint task representation of lifting one's finger together with one's co-actor.

This finding extends previous research on imitation between groups that has led to similar theoretical conclusions (Essa et al., 2019; Ramenzoni et al., 2014; Tsai et al., 2011; see McEllin et al., 2018 and Milward & Sebanz, 2016 for discussion). While these studies showed that *external observation* of individual and joint actions can prime the execution of individual and joint actions respectively, our study goes one step further by showing that the *internal anticipation* of individual or joint action in others can produce similar effects. As such, our findings tap into the endogenous action planning processes that guide the initiation and control of joint actions in a goal-directed rather than stimulus-driven way, providing direct support for the idea that task representations encoding group-level performance (i.e., “we-representations”) can play a role in joint action planning (Formica & Brass, 2024; Kourtis et al., 2019).

In summary, our study provides initial evidence that anticipated imitation effects can be modulated by congruency relations between interacting groups. This finding indicates that people can use anticipated actions of multiple other agents to initiate and control their own contributions to a social interaction and supports the idea that actions performed together with others become represented in relation to group-level rather than individual-level performance. Limiting our findings, it remains to be determined why not all participants in the current study showed to be affected by predictable responses of other agents in the scene. Future research should explore task conditions that may foster the integration of others’ anticipated actions into people’s own action representations. For instance, task instructions that emphasize action-outcome contingencies over stimulus-response mappings in the present setup may enhance sensitivity to the imitative behaviour of others. In addition, the presence of physical rather than virtual co-actors may further promote the integration of their actions into people’s task representations. Further studying effects of anticipated imitation between groups (i.e., between “us” and “them”) provides exciting opportunities to investigate the content and structure of joint task representations and we hope to stimulate future research on this topic.

CRediT authorship contribution statement

Maximilian Marschner: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft. **Carl Michael Galang:** Conceptualization, Methodology, Supervision, Writing – review and editing. **Marcel Brass:** Conceptualization, Methodology, Supervision, Resources, Funding acquisition, Writing – review and editing.

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Declaration of competing interest

The author declares that they have no conflict of interest.

Appendices

Table A1

Full ANOVA results for the explorative IES analysis

Effect	df	*F*	*p*	η_p^2
Task Condition	1, 233	0.38	.536	.002
Imitative Response	1, 233	0.20	.657	< .001
RT Group	1, 233	323.5	< .001	.581
Task Condition × Imitative Response	1, 233	3.81	.052	.016
Task Condition × RT Group	1, 233	2.08	.151	.009
Imitative Response × RT Group	1, 233	1.15	.284	.005
Task Condition × Imitative Response × RT Group	1, 233	6.61	.011	.028

Note: Inverse Efficiency Scores (IES) were analyzed by means of a 2 (Task Condition: Individual Action vs. Joint Action) x 2 (Imitative Response: Individual Imitation vs. Joint Imitation) x 2 (RT Group: Fast Responder vs. Slow Responder) mixed ANOVA with Task Condition and Imitative Response as within- and RT Group as between-subjects factors.

Table A2

Full ANOVA results for the follow-up IES analysis of slow responder

Effect	df	*F*	*p*	η_p^2
Task Condition	1, 116	0.30	.588	.003
Imitative Response	1, 116	0.87	.352	.007
Task Condition × Imitative Response	1, 116	7.21	.008	.059

Note: Inverse Efficiency Scores (IES) were analysed by means of a 2 (Task Condition: Individual vs. Joint Action) x 2 (Imitative Response: Individual vs. Joint Imitation) repeated measures ANOVA with Task Condition and Imitative Response as within-subjects factors.

Table A3

Full ANOVA results for the follow-up IES analysis of fast responder

Effect	df	*F*	*p*	η_p^2
Task Condition	1, 117	2.48	.118	.021
Imitative Response	1, 117	0.29	.593	.002
Task Condition × Imitative Response	1, 117	0.33	.569	.003

Note: Inverse Efficiency Scores (IES) were analysed by means of a 2 (Task Condition: Individual vs. Joint Action) x 2 (Imitative Response: Individual vs. Joint Imitation) repeated measures ANOVA with Task Condition and Imitative Response as within-subjects factors.

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