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Anticipated imitation of multiple agents

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ABSTRACT

It is well-established that people tend to mimic one another's actions, a crucial aspect of social interactions. Anticipating imitation has been shown to boost motor activation and reaction times for congruent actions. However, prior research predominantly focused on dyads, leaving gaps in our knowledge regarding group dynamics. This study addresses this gap, conducting three experiments using extensive online data. Participants engaged in anticipated imitation tasks with one versus three virtual agents. The results across all three experiments ($n = 77$; $n = 239$; $n = 457$) consistently support the existence of an anticipated imitation effect, with faster reaction times for congruent actions. Furthermore, the research unveils a social facilitation effect, with participants reacting more swiftly when anticipating three agents compared to one. However, we did not find the expected increase of the congruency effect with multiple agents; rather, the data indicates that anticipating multiple agents instead decreases this effect. These findings are discussed within the framework of ideomotor theory, offering insights into how they relate to recent research on the automatic imitation of multiple agents.

1. Introduction

It is now well established that humans tend to copy each other's behaviours and that such copying plays a crucial role for successful social interactions (Heyes, 2011). Ideomotor theory suggests that this ability arises as the result of shared coding between actions and closely associated sensory outcomes (e.g., Hommel, 2009; Prinz, 1997). Strong evidence for this model comes from work on automatic imitation, which is one type of copying action that occurs both automatically and covertly during action observation (e.g., Brass et al., 2000; Cracco et al., 2018; Cracco & Brass, 2019; Heyes, 2011). Work in this area convincingly shows that response times to an imperative (often symbolic) cue are faster when also observing the same action in the background, while response times are slower when observing a different and incompatible action (Brass et al., 2000; for a recent meta-analysis and review, see Cracco et al., 2018). Such facilitation/interference indicates that motor plans are indeed influenced by visual observations of compatible/incompatible movements, suggesting shared representation of both.

A related but distinct phenomenon is *anticipated* imitation. Whereas automatic imitation occurs during the observation of another's action, anticipated imitation instead focuses on the person making the initial action (with the knowledge that they will be imitated). As with automatic imitation, ideomotor theory also predicts facilitation/interference effects with compatible/incompatible anticipated actions due to the shared coding of motor plans and the linked sensory outcome (e.g., anticipating someone raising their hands after me should also activate representations of raising my hand; also see the Sociomotor Theory of Action Control – Kunde et al., 2018). Work on anticipated imitation has generally followed action-effect paradigms, wherein participants perform actions that trigger predictable sensory outcomes; crucially, such outcomes can either be compatible or incompatible with the action on some dimension. For example, a classic study by Kunde (2001) reported that participants showed faster reaction times when the spatial location of their keypresses were congruent with the spatial location of the visual outcome (relative to when the spatial location was incongruent).

Pfister et al. (2013) provided initial evidence that such anticipated action effects also occur for imitation. In their study, participants were paired and either took on the role of the "model" or the "imitator". The model responded to an imperative cue with either a short or long keypress. The imitator was tasked with either imitating the short or long keypress, or to counter imitate by performing the opposite action. Crucially, the experiment was conducted in blocks in which the model had knowledge of whether they would be imitated or not on any given

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trial. They report that the imitator showed faster responses when they were tasked to imitate the model as opposed to counter imitate, thus replicating previous work on automatic imitation. Crucially, they also report that the model showed similar effects – faster reaction times to the imperative cue when they *anticipated* being imitated vs. counter imitated.

Although not as widely investigated as automatic imitation, there is now a substantial body of evidence supporting the existence of anticipated imitation effects (for a recent review, see Neszmelyi et al., 2022), as well as social anticipation effects more generally. For example, Muller (2016) extended Pfister et al. (2013) original findings by showing similar anticipation effects between dyads even when the actions were not exactly the same between the model and imitator. Pfister et al. (2017) followed up their original findings by showing that anticipated imitation effects are indeed caused by the compatibility of actions (e.g., a congruency effect) as opposed to the temporal delay between the model and imitators' actions. Dignath et al. (2017) showed that their participants' preferred partners who showed predictable and immediate responses (regardless if they were the imitator or the one being imitated), which they argue links anticipated imitation with social affiliation effects. In an interesting set of experiments, Weller et al. (2019) investigated whether anticipated imitation effects were the result of anatomical or spatial congruency/incongruency. Using finger lifting actions between the model and imitator, they found evidence to suggest that the latter (i.e., spatial) is primarily driving these effects (although see Bunlon et al., 2015). In another study by Weller et al. (2020), they report that in-group bias (manipulated via the minimal group paradigm) did *not* influence anticipated imitation effects measured using the same task as first reported by Pfister et al. (2013); this interestingly matches recent work showing that group membership also does not influence automatic imitation effects (Genschow et al., 2022; De Souter et al., 2021). Finally, work by Rocca and Cavallo (2021) show that action anticipation also influences the behavioural kinematics of the model, providing evidence that action anticipation effects extend beyond reaction time paradigms.

An outstanding issue in this line of work, however, is the exclusive use of dyads (either with two interacting participants or one participant interacting with a virtual agent). In contrast, actions are not done solely by individuals or pairs; indeed, the ability to work together in large groups and perform similar and complementary actions to achieve some goal (e.g., building a house) undoubtedly played an essential role in the flourishing of human societies. Interestingly, previous work on automatic imitation, which as outlined above is thought to rely on similar processes, suggests that the motor system simultaneously simulates multiple agents' actions. Cracco et al. (2015) were the first to show that observing two identical and congruent (to the observer) movements leads to stronger automatic imitation effects. Crucially, they provide evidence that this effect cannot be explained by increased attentional salience of observing multiple actions, but instead seems to be better explained via ideomotor theory as this effect was stronger when observing human hands perform actions vs. wooden hands. In a follow up study, Cracco and Brass (2018a) showed that this effect was not due to random representation of a single hand, as it still occurred even when participants were cued to only pay attention to a single hand. Cracco and Brass (2018b) also showed that different incompatible actions can be represented in the motor system simultaneously (evident as a weaker automatic imitation effect when observing both congruent and incongruent actions at the same time compared to multiple congruent imitators). Interestingly, this facilitation effect seems to asymptote for congruent actions after observing two or more hands, while incongruent actions show a linear interference effect; however, the asymptotic trend with congruent trials becomes linear when removing incongruent trials (Cracco & Brass, 2018c). Further evidence has also been provided via neural measures such as TMS (Cracco et al., 2016), fMRI (Cracco et al., 2019), and EEG (via frequency tagging; Cracco, Bernardet, et al., 2022). All in all, this line of work convincingly shows that the motor system simultaneously simulates multiple agents' actions (also see Cracco & Cooper, 2019; Cracco, Braem, & Brass, 2022; Cracco, Lee, et al., 2022). Given all of this, an important and outstanding question is if these group effects also emerge also for *anticipated* imitation. The aim of the current studies is to fill this gap in the literature.

Given the reviewed work on multi-agent automatic imitation, we predict that anticipating the action of multiple agents will have similar facilitatory/interference effects on the motor system which should behaviourally manifest as faster/slower reaction times. This prediction is also congruent with ideomotor theory, as anticipating congruent imitative actions by multiple others should lead to increased motor activation, which in turn should lead to faster reaction times (and vice versa for anticipating incongruent actions). It is important to note, however, that although automatic and anticipated imitation share a number of resemblances, they are not the same phenomenon. This is evident on work investigating the role of spatial congruency effects on automatic and anticipated imitation – wherein the former there is strong evidence to show that spatial congruency cannot fully account for automatic imitation (Cracco et al., 2018), in the latter the evidence is more mixed with work by Weller et al. (2019) suggesting that spatial congruency can entirely explain the effects. Furthermore, different mechanisms are at play, as automatic imitation is thought to be due to the activation of motor representations of the observed stimulus, for anticipated imitation it is instead the anticipation of the stimulus that activates motor representation; in other words, whereas the former is driven by how we represent specific stimuli, the latter is drive by how we represent future events. As such, it is possible a divergence between the two phenomena will also be seen when investigating multi-agent actions.

To test these hypotheses, we executed three experiments wherein participants responded with an index or middle finger lift to imperative cues "1" or "2", respectively. 3D modeled hands were shown in the background also performing index or middle finger lifts. These actions were presented *after* the participant made their own action and congruent/incongruent trials were separately blocked such that the participant could anticipate if the model would imitate or counter imitate their action. Crucially, participants either observed one hand or three hands imitate or counter imitate them, thus allowing us to directly test whether multi-agent action anticipation influences anticipated imitation. Experiment 1 was the initial exploratory study, while experiment 2 aimed to directly replicate these preliminary results using a larger sample. Experiment 3 was conducted to address a possible visual confound in the first two experiments.

2. Experiment 1

2.1. Methods

2.1.1. Transparency and openness

The raw and processed data along with the appropriate processing script can be found at: https://osf.io/5zm3d/. Across all three experiments we report our sample sizes, how they were determined, all data exclusions. Note that we did not pre-register experiment 1 as we considered it exploratory. However, both experiments 2 and 3 have pre-registrations available. Furthermore, note that we originally pre-registered traditional parametric tests (i.e., ANOVA) for experiment 2, but realized for experiment 3 that non-parametric tests were needed due to the skewness of the data (normality was checked for all three experiments in the end). As a result, we originally chose to present both parametric and non-parametric results side-by-side. After some feedback, however, we opted to simply present the non-parametric tests. For maximum transparency, we have included a supplementary file that contains the parametric results. Based on further feedback, we have also opted to present Bayesian analyses to supplement the frequentist approach for each experiment – this decision was also post-hoc and Bayesian analyses were not pre-registered. Note that, regardless of how one analyzes the data, our overall interpretations and discussion do not change. Lastly, note that all samples were collected via an online platform, with participants being right-handed and fluent in English. This means that there are important constraints to the generalizability of our results, and it would be up to future work to shed further light on this topic.

2.1.2. Participants

As experiment 1 was our initial foray into investigating this topic, we did not have any strong intuitions about the sort of effect size (for the interaction effect) we should expect. As such, we opted to collect $n = 80$ participants as a starting point (this sample size is also larger than previous anticipated imitation studies). Three of these participants were removed due to not using their right hand for the experiment leaving a final sample of $n = 77$ ($M_{age} = 27.5$, $SD_{age} = 8.7$; female = 37).[1] Participant recruitment was conducted via Prolific.co which has been shown to provide quality samples for behavioural experiments relative to alternative online participant recruitment platforms (Palan & Schitter, 2018; Peer et al., 2017). All participants were filtered to be right-handed, fluent in English, and were compensated £2 for participation. Data collection started and ended on April 29, 2022. This study was approved by the HU-Berlin Psychology Ethics Committee.

2.1.3. Apparatus and stimuli

The experiment was programmed using JavaScript and the jsPsych library (ver. 6.1; De Leeuw, 2015). We specifically utilized and adapted code provided by Westfal et al. (2020) to program the main task, as Westfal et al. (2020) have recently shown that automatic imitation data collected using an online sample are equivalent to data collected in the lab. The experiment files and data were stored on JATOS (Just Another Tool for Online Studies; Lange et al., 2015). The main stimuli used for the experiment were created via Blender and consisted of a Caucasian hand observed top down from the first-person perspective. In the baseline picture, the hand(s) was shown resting with no finger lifted. In the experimental conditions the hand(s) were shown to be either lifting their index of middle finger. The stimuli consisted of either a single hand or three hands side by side. The numbers “1” or “2” were presented just above the hand (or in the case of three hands, the middle hand) to act as the imperative cue for the participants to make their own finger lifts. See Fig. 1A.

2.1.4. Design

The experiment used a 2 × 2 within-subjects design with # of Hands (One, Three) and Congruence (Congruent, Incongruent) as the factors. The experiment consisted of 160 trials with 40 trials per fully crossed 2 × 2 conditions (i.e., One-Congruent, One-Incongruent, Three-Congruent, Three-Incongruent). As participants needed to accurately predict the movement of the observed hand(s), each fully crossed 2 × 2 condition was blocked; however, we opted to do so at the level of # of Hands such that the first two blocks would always be One or Three hand (s) and the last two would be whichever # of Hands was not shown first. We randomized whether the Congruent or Incongruent block would be shown first within this higher order nesting (e.g., an example timeline would be: [One-Incongruent], [One-Congruent], [Three-Congruent], [Three-Incongruent]). The imperative cues (“1”, “2”) were fully randomized within each block. Following previous work showing effects of anticipated imitation, the main dependent variable were reaction times. Note that while previous work on anticipated imitation has generally not shown statistically significant effects of error rate (e.g., Pfister et al., 2013; Muller, 2016, Weller et al., 2019, 2020), as work in this area often reports both reaction times and error rates, we do so for completeness here as well.

[1] Two participants did not disclose their age or gender.

2.1.5. Procedure

Participants were instructed that they would be responding to two imperative cues: “1” and “2” with their right index and middle finger, respectively. To do so, participants were instructed to hold down the “V” and “B” keys of their keyboard and to lift the appropriate finger as fast and as accurately as they could after seeing the imperative cue appear. Participants were also informed that one or three hands would move in the background but to ignore them and focus on the task. Each block started with information about how many hands the participant would see and whether the hand(s) would perform the correct or wrong finger lift relative to the imperative cue. Before beginning the block, participants first completed 10 practice trials with feedback. Afterwards, participants were informed that they would begin the main trials and that they would *not* be provided feedback. The trial-by-trial breakdown is as follows: first, participants were shown the neutral image of the hand(s) for 1000 ms. After this duration, an imperative cue (“1” or “2”) would appear to prompt the participant to make a response. Once the participant made a response, the hand(s) in the background lifted the index or middle finger depending on the block – this occurred immediately after the participants’ response. This finger lift image would last for another 1000 ms before the next trial began. See Fig. 1B.

2.1.6. Analysis plan

We originally planned to conduct a 2 × 2 within-subjects ANOVA with # of Hands (One, Three) and Congruence (Congruent, Incongruent) as the factors. However, as the data is not normally distributed (checked via Shapiro-Wilk test for normality and visually inspecting Q-Q plots of the residuals (per condition, as well as difference scores for the relevant main effects) – see OSF page for these analyses), we decided to report the equivalent non-parametric tests via Wilcoxon signed-rank tests. Our logic for this decision was as follows. Given that each of our conditions only have two levels (i.e., congruent vs. incongruent; one hand vs. three hands), then any effect from a repeated measures ANOVA can be transformed into a paired samples *t*-test as $F = t\,\hat{}\,2$ when the numerator $df = 1$ (and since our conditions only have two levels, this assumption is met). In other words, the main effects of the ANOVA can be transformed (via averaging across the appropriate condition) to get an equivalent result using a t-test. For the interaction effect, this can also be done by simply using difference scores (as the 2-way interaction is simply a difference of a difference). Given that the Wilcoxon signed-rank test is the non-parametric equivalent of a paired sample t-test, then we reasoned that this test would provide us with the appropriate non-parametric test for both main effects and the interaction effect observed in the original ANOVA. Note that the effect size for the Wilcoxon signed-rank test is computed by JASP using the Rank-Biserial Correlation. We also report Bayesian Wilcoxon tests and follow guidelines set by Jeffreys (1961) for interpretation wherein $BF > 0.33$ & $BF < 3$ is considered inconclusive or “anecdotal” (also see Jarosz & Wiley, 2014). Statistical analysis was conducted via JASP (ver. 0.18), with default priors (as set by JASP) used (a Cauchy distribution centred at 0 with a scale of 0.7). Incorrect responses and responses below 100 ms and above 3 SD of the participants’ mean were removed before final analysis (~3.9% of total trials on average). The data was averaged across individual trials per condition. To provide more information regarding the distribution of the raw data, we also provide raincloud plots (created via JASP) – See Fig. 2.

2.2. Results

2.2.1. Frequentist analyses

2.2.1.1. Reaction times. The analysis revealed a significant main effect of Congruence [$W = 1104$, $p = 0.044$, $|r| = 0.27$] wherein participants responded faster in the Congruent blocks [Median = 451 ms, IQR = 85 ms] compared to the Incongruent blocks [Median = 464 ms, IQR = 91

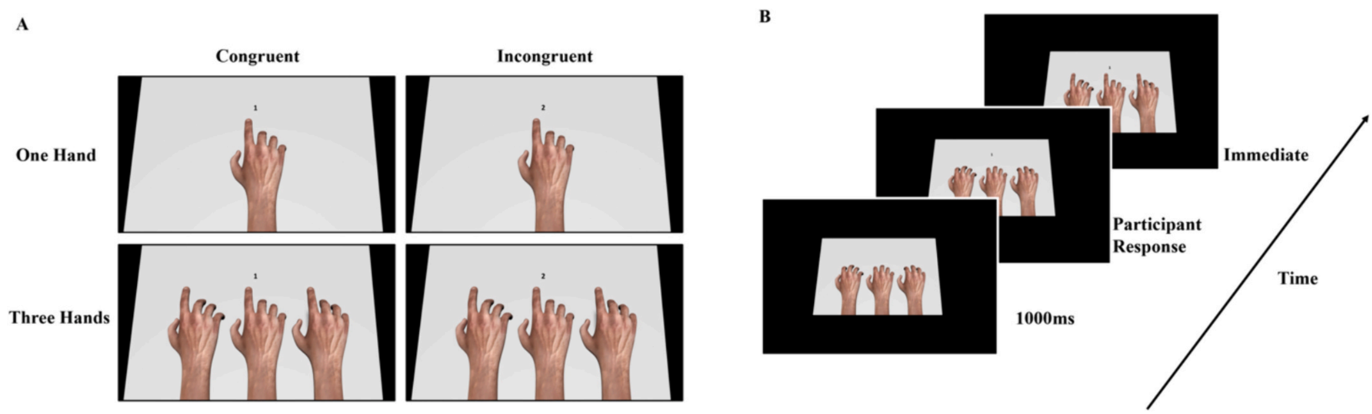

Fig. 1. A) Overview of conditions. B) Example of a single trial.

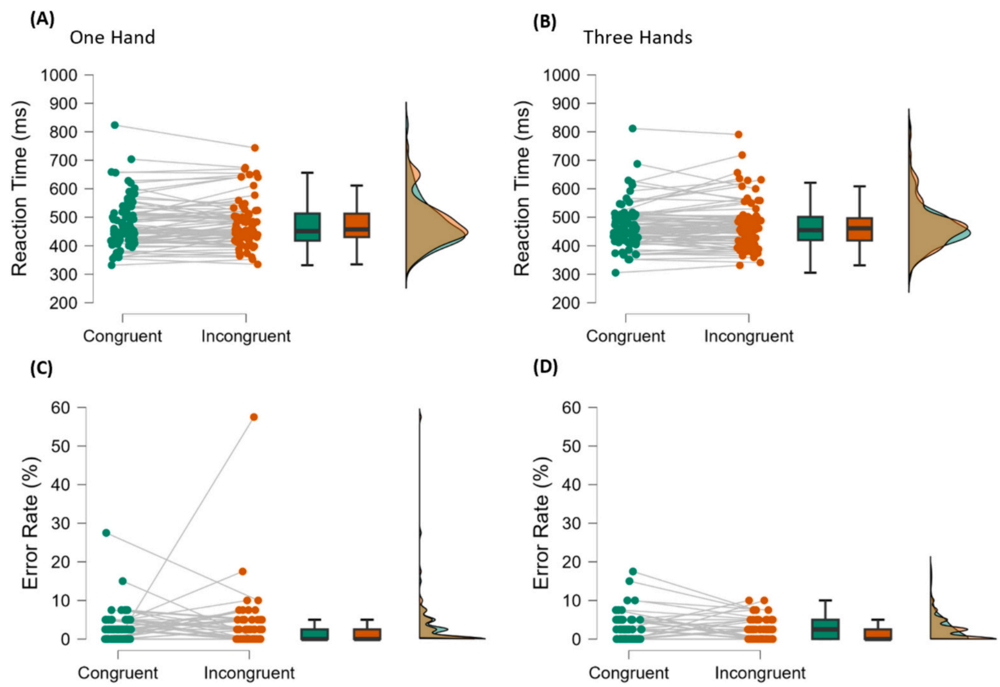

Fig. 2. Raincloud plots of each condition in Experiment 1. (A) and (B) for RT and (C) and (D) for ER data. (A) and (C) for the One Hand condition, and (B) and (D) for the Three Hands condition. Green for congruent trials and orange for incongruent. Each dot represents a single participant, with the line between the dots connecting their scores across conditions. To the right are the data represented using boxplots and histogram respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ms]. The analysis also showed a statistically significant main effect of # of Hands [W = 1915, p = 0.036, |r| = 0.28], wherein participants responded faster at Ona Hand [Median = 454 ms, IQR = 90 ms] compared to Three Hands [Median = 459 ms, IQR = 74 ms]. However, no significant interaction effect was found [W = 1599, p = 0.62, |r| = 0.065]. See Fig. 3A and B.

The Bayesian analysis revealed BF10 = 1.39 for the main effect Congruence, BF10 = 1.2 for the main effect of # of Hands, and BF10 = 0.13 for the interaction effect.

2.2.1.2. Error rates. We found no statistically significant effects on the error rates [Congruence: W = 550, p = 0.35, |r| = 0.16; # of Hands: W = 442, p = 0.88, |r| = 0.028; Interaction: W = 421, p = 0.67, |r| = 0.08]. See Fig. 3C and D.

The Bayesian analysis revealed BF10 = 0.22 for the main effect of Congruence, BF10 = 0.11 for the main effect of # of Hands, and BF10 = 0.136 for the interaction effect.

2.3. Discussion

Looking at the frequentist results, the results of this first experiment successfully replicated previous work on anticipated imitation; the results suggest that participants were faster to respond when they anticipated being imitated by the hand(s) on the screen compared to when they anticipated the hand(s) to do the opposite action. We also found a significant effect of # of Hands, wherein participants were faster when anticipating one hand make an action, regardless if they were imitative (although note that while this is true for the median, the mean reaction times show the opposite results). Crucially, in regards to the interaction effect, we did not find sufficient evidence to suggest that the number of anticipated hands influenced the effect of anticipated imitation. It is possible then that, unlike its automatic counterpart, anticipating multiple agents' actions does not lead to an additive effect (of multiple agents) in the motor output of the anticipator. This may be due to the fact that, with automatic imitation, the model is directly observing the

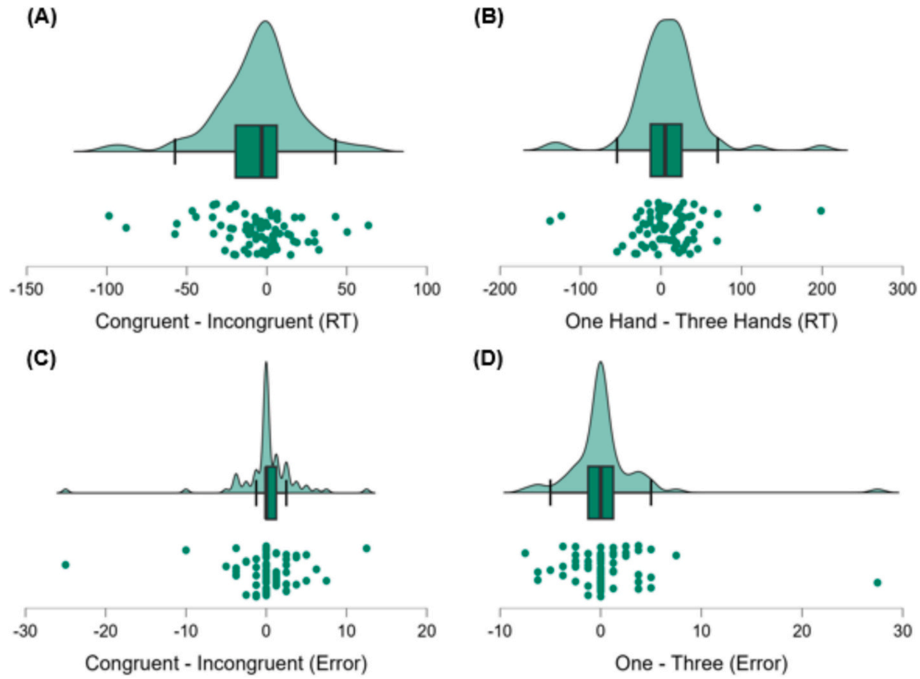

Fig. 3. (A) Raincloud plot of the main effect of Congruence for reaction times. (B) Raincloud plot of the main effect of # of Hands for reaction times. (C) Raincloud plot of the main effect of Congruence for error. (D) Raincloud plot of the main effect of # of Hands for error. Each dot represents a single participant's difference score. To the right are the data represented using boxplots and histogram respectively.

actions which may lead to stronger activations in the motor system. On the other hand, anticipation implies that the model is merely imagining the actions, which may not be represented in the motor system in such a way that would lead to increased facilitation/interference in their motor output (although this goes against the predictions of ideomotor theory). However, a major caveat to these results is that the significant results were rather weak. Indeed, the Bayesian analyses suggests that both main effects were inconclusive, while there is substantial evidence (BF01 = 7.7 [1/0.13]) for the null hypothesis relative to the alternative for the interaction effect. As such, to corroborate these findings we opted to run a second experiment with a larger sample size. In particular, we were quite interested in seeing if we would find evidence for a main effect of # of Hands with a high-powered study.

3. Experiment 2

3.1. Methods

3.1.1. Participants

As per our pre-registration, we aimed to collect $n = 239$ based on an a priori power analysis conducted via G*Power (Faul et al., 2007; Faul et al., 2009). Note that we conducted the power analysis using a pairwise *t*-test design, as we initially powered the study with the main effect of # of Hands in mind. As this factor only has two levels (One, Three), then the term in the ANOVA can be transformed to an equivalent t-test (as F = t ˆ 2, when the numerator df = 1). As such, on G*Power, we used a paired-samples t-test assuming an effect size of dz. = 0.182 at 80% power (two-tailed, alpha at 0.05) to get our sample size. Overall, we collected 254 participants as 8 participants were removed for not exclusively using their right hand during the experiment and 7 participants were removed due to having >20% of their trials removed (see pre-registration). As such, our final sample size was our intended n = 239 ($M_{age} = 28.8$, $SD_{age} = 9.3$; female = 122).[2] All participants were filtered to be right-handed, fluent in English, and were compensated £2 for participation. Data collection occurred on June 22–23, 2022. This study was approved by the HU-Berlin Psychology Ethics Committee.

3.1.2. Apparatus and stimuli

No changes from experiment 1.

3.1.3. Design

No changes from experiment 1.

3.1.4. Procedure

No changes from experiment 1.

3.1.5. Analysis plan

No changes from experiment 1. Incorrect responses and responses faster than 100 ms and slower than 3 SD of the participants' mean were removed before final analysis (~4% of total trials on average). To provide more information regarding the distribution of the raw data, we also provide raincloud plots (created via JASP) – See Fig. 4.

3.2. Results

3.2.1. Frequentist analyses

3.2.1.1. Reaction times. The analysis revealed a significant main effect of Congruence [W = 10,988, $p = 0.002$, |r| = 0.23], wherein participants responded faster in the Congruent blocks [Median = 462 ms, IQR = 90 ms] compared to the Incongruent blocks [Median = 466 ms, IQR = 90 ms]. The analysis also yielded a statistically significant main effect of # of Hands [W = 18,180, $p < 0.001$, |r| = 0.27] wherein participants responded faster when anticipating Three Hands [Median = 459 ms, IQR = 86 ms] compared to One Hand [Median = 467 ms, IQR = 99 ms]. The interaction effect was not statistically significant [W = 15,474, $p = 0.29$, |r| = 0.08]. See Fig. 5A and B.

The Bayesian analysis revealed BF10 = 21.57 for the main effect of Congruence, BF10 = 8.67 for the main effect of # of Hands, and BF10 =

[2] Four participants did not disclose their age or gender, while an extra participant disclosed their gender but not their age.

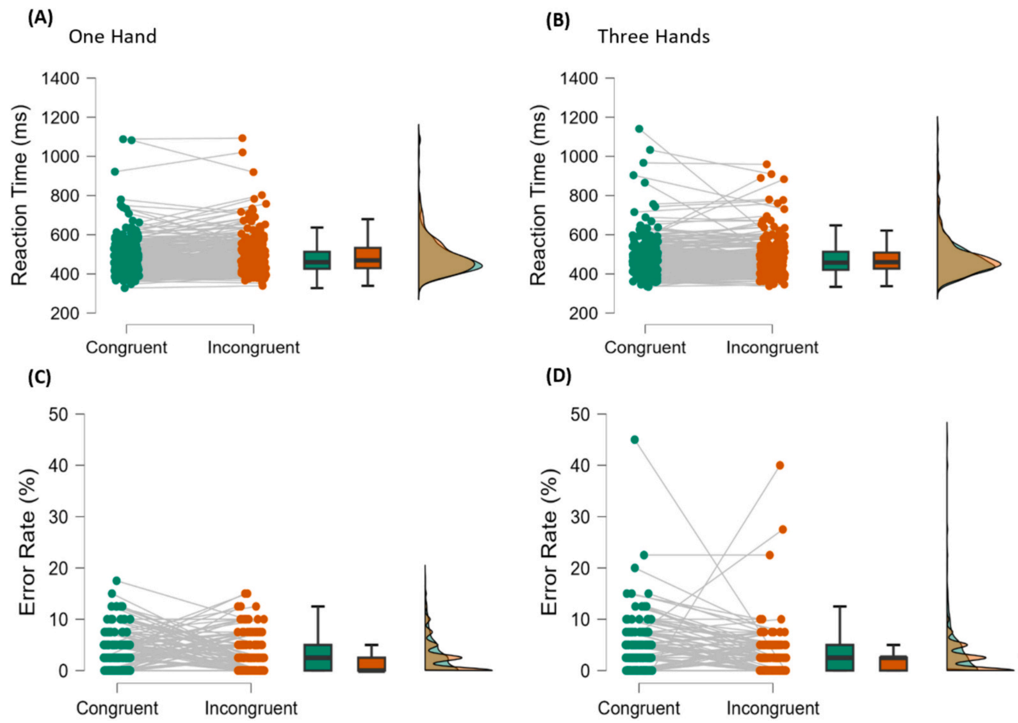

Fig. 4. Raincloud plots of each condition in Experiment 2. (A) and (B) for RT and (C) and (D) for ER data. (A) and (C) for the One Hand condition, and (B) and (D) for the Three Hands condition. Green for congruent trials and orange for incongruent. Each dot represents a single participant, with the line between the dots connecting their scores across conditions. To the right are the data represented using boxplots and histogram respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

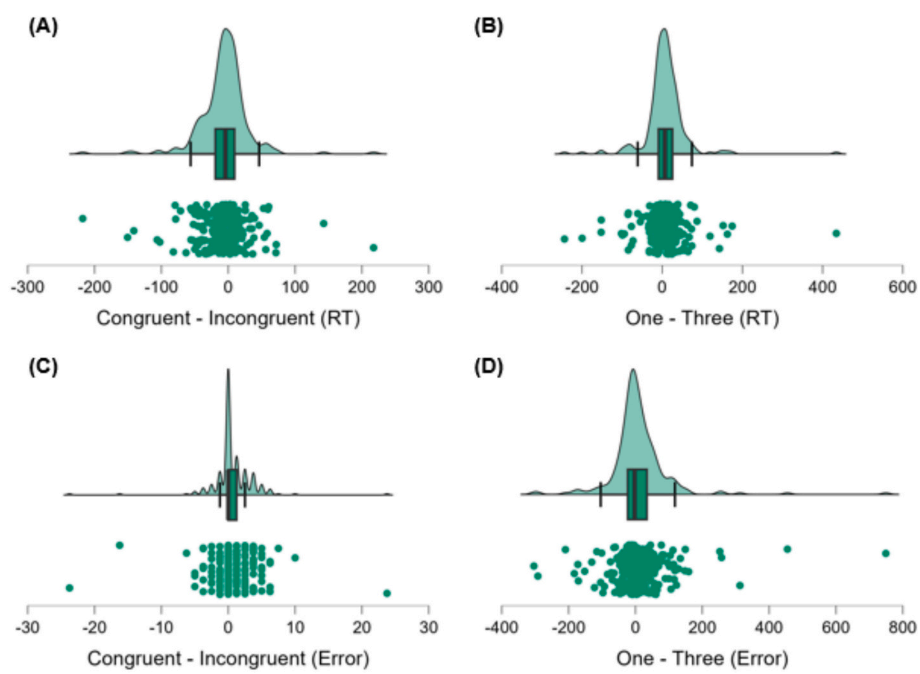

Fig. 5. (A) Raincloud plot of the main effect of Congruence for reaction times. (B) Raincloud plot of the main effect of # of Hands for reaction times. (C) Raincloud plot of the main effect of Congruence for error. (D) Raincloud plot of the main effect of # of Hands for error. Each dot represents a single participant's difference score. To the right are the data represented using boxplots and histogram respectively.

0.17 for the interaction effect.

3.2.1.2. Error rates. Regarding the error rates, the analysis yielded a statistically significant main effect of Congruence [W = 6302.5, $p < 0.001$, $|r| = 0.44$] wherein participants made more mistakes in the Congruent condition [Median = 2.5%, IQR = 5%] compared to Incongruent [Median = 1.3%, IQR = 3.8%]. The main effect of # of Hands [W = 5110, $p = 0.94$, $|r| = 0.007$] and the interaction [W = 5600, $p = 0.36$, $|r| = 0.09$] were not statistically significant. See Fig. 5C and D.

The Bayesian analysis revealed BF10 = 134.8 for the main effect of

Congruence, BF10 = 0.072 for the main effect of # of Hands, and BF10 = 0.096 for the interaction effect.

3.3. Discussion

When looking at the frequentist results, the results of experiment 2 successfully replicated the anticipated imitation effect found in experiment 1 – participants showed faster responses when anticipating a congruent action from the hand(s) relative to incongruent. Furthermore, we again found a significant effect of # of Hands; however, this time participants generally responded faster when anticipating three hands compared to just one (which was also true for the means). Finally, we again did not find evidence to suggest that anticipated imitation is affected by multiple agents. These results are also corroborated by our Bayesian analyses reinforce our initial idea that directly observing multiple agents imitate one's action versus merely imagining such a scenario differentially affects motor output. Indeed, given the now significant main effect of # of Hands, it is possible that there may be a type of anticipated social facilitation effect that occurs during action anticipation. However, one potential confounds in both experiments 1 and 2 are the stimuli. In particular, it is possible that visually only seeing one hand versus multiple hands is driving this social facilitation effect. As such, before interesting these results, we opted to conduct a third experiment where we update our one hand stimuli such that two hands are also flanking it (just like in the stimuli with three hands; See Fig. 6).

As a final note, we also found a statistically significant main effect of Congruence with the error rates (with the Bayesian analysis also suggesting substantial evidence for the alternative relative to the null hypothesis); however, this was in the opposite to the expected direction (with participants making *more* errors in congruent vs. incongruent conditions). Given that we did not find this result in experiment 1 and the counter intuitive nature of it, we opted to first corroborate it in another experiment before interpreting it.

4. Experiment 3

4.1. Methods

4.1.1. Participants

As per our pre-registration, we aimed to collect $n = 457$ based on an a priori power analysis assuming an effect size of dz. = 0.134 at 80% power (two-tailed, alpha at 0.05). The effect size estimate was based on our previous study on the main effect of # of Hands. Also note that we used G*Power to calculate this sample size for a Wilcoxon signed-rank test as our previous results yielded a non-normal distribution (see *Transparency and Openness section)*. Overall, we collected 492 participants as 28 participants were removed for not exclusively using their right hand during the experiment and 7 participants were removed due to having >20% of their trials removed (see pre-registration). As such, our final sample size was our intended n = 457 (M_{age} = 29.3, SD_{age} = 9.8; female = 233).[3] All participants were filtered to be right-handed, fluent in English, and were compensated £1.5 for participation (compensation was lowered for this experiment due to resource constraints as a result of the increased sample size). Data collection occurred on October 24–25, 2022. This study was approved by the HU-Berlin Psychology Ethics Committee.

4.1.2. Apparatus and stimuli

The stimuli for the One Hand condition was updated to include two other hands flanking the original middle hand. These hands do not make any actions (see Fig. 6 above). No other changes from experiments 1 and 2.

[3] Three participants did not disclose their age, one of which also did not disclose their gender.

4.1.3. Design

No changes from experiment 1 and 2.

4.1.4. Procedure

No changes from experiment 1 and 2.

4.1.5. Analysis plan

No changes from experiment 1 and 2. Incorrect responses and responses faster than 100 ms and slower than 3 SD of the participants' mean were removed before final analysis (~4% of total trials on average). To provide more information regarding the distribution of the raw data, we also provide raincloud plots (created via JASP) – See Fig. 7.

4.2. Results

4.2.1. Frequentist analyses

4.2.1.1. Reaction time. The analysis revealed a significant main effect of Congruence [W = 37,963, $p < 0.001$, $|r| = 0.27$], wherein participants responded faster in the Congruent blocks [Median = 463 ms, IQR = 87 ms] compared to the Incongruent blocks [Median = 465 ms, IQR = 89 ms]. The analysis also yielded a statistically significant main effect of # of Hands [W = 60,404, $p = 0.004$, $|r| = 0.15$], wherein participants responded faster when anticipating Three Hands [Median = 461 ms, IQR = 88 ms] compared to One Hand [Median = 465 ms, IQR = 83 ms]. See Fig. 8A and B. The interaction effect was statistically significant [W = 58,706, $p = 0.024$, $|r| = 0.12$]. Follow-up tests to break down this interaction showed that while there was a significant difference between Congruence in the One Hand condition [W = 39,525, $p < 0.001$, $|r|$ = 0.25], this was not the case for the Three Hands condition [W = 47,180, $p = 0.07$, $|r| = 0.1$].

The Bayesian analysis revealed BF10 = 2372 for the main effect of Congruence, BF10 = 7.7 for the main effect of # of Hands, and BF10 = 0.98 for the interaction effect.

4.2.1.2. Error rates. Regarding the Error Rates, the analysis yielded a statistically significant main effect of Congruence [W = 23,587, $p < 0.001$, $|r| = 0.28$] wherein participants made more mistakes in the Congruent condition [Median = 2.5%, IQR = 3.8%] compared to Incongruent [Median = 1.3%, IQR = 3.8%]. The main effect of # of Hands [W = 14,884, $p = 0.12$, $|r| = 0.11$] and the interaction [W = 16,816, $p = 0.74$, $|r| = 0.024$] were not statistically significant. See Fig. 8C and D.

The analysis revealed BF10 = 82 for the main effect of Congruence, BF10 = 0.17 for the main effect of # of Hands, and BF10 = 0.06 for the interaction effect.

4.3. Discussion

The results of experiment 3 directly replicates the findings reported in experiment 2 while controlling for the number of presented hands on the screen. Importantly, the Bayesian analyses now provide stronger evidence for the alternative relative to null for both main effects – 7.7 times more likely for the main effect of # of Hands (suggesting substantial evidence for the alternative hypothesis relative to null) and 2372 times more likely for the main effect of Congruence (suggesting "very strong" evidence for the alternative hypothesis relative to the null). We now also found that the interaction effect is statistically significant. This interaction effect is interesting, as the results are in the opposite direction of our prediction. Based on work on automatic imitation of multiple agents we hypothesized that, if there was a statistically significant interaction effect, there should be a stronger congruence effect when anticipating three hands compared to one. However, we instead see the complete opposite pattern. It is not entirely clear why this is the case. Of course, an important caveat is that we only

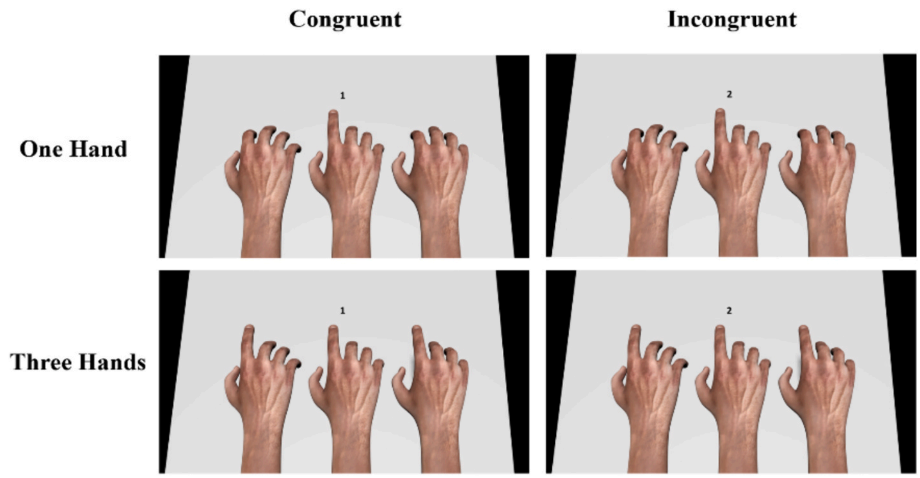

Fig. 6. Overview of conditions with the updated stimuli for the One Hand condition.

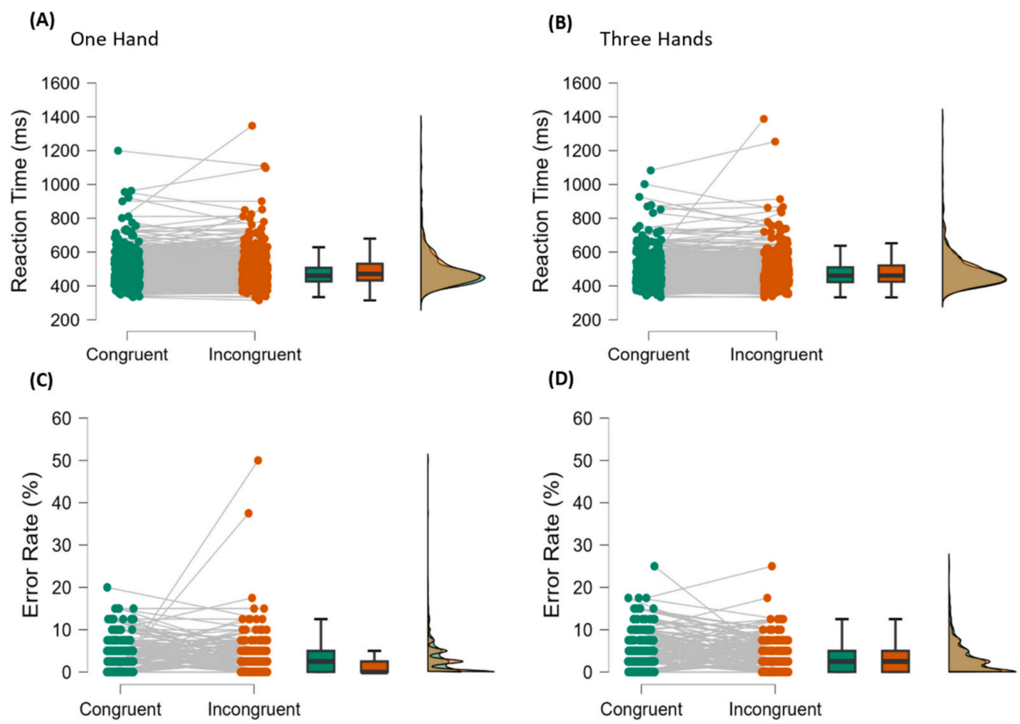

Fig. 7. Raincloud plots of each condition in Experiment 3. (A) and (B) for RT and (C) and (D) for ER data. (A) and (C) for the One Hand condition, and (B) and (D) for the Three Hands condition. Green for congruent trials and orange for incongruent. Each dot represents a single participant, with the line between the dots connecting their scores across conditions. To the right are the data represented using boxplots and histogram respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

found this statistically significant interaction effect in this last experiment. Perhaps this was due to power issues – and indeed, we only powered these experiments in relation to the main effect of # of Hands. As such, it is possible that this 2 × 2 interaction effect can only be found in large samples. Furthermore, the Bayesian analysis suggests that the data cannot distinguish between the null and alternative hypotheses, which further puts doubt at the robustness of this finding. Finally, both the frequentist and Bayesian analyses corroborate the error rate effect of Congruence found in experiment 2. However, before discussing these findings all together, we opted to take advantage of our overall large sample ($n = 773$) and do a final combined analysis.

5. Combined analyses

5.1. Frequentist analyses

5.1.1. Reaction time

The analysis revealed a significant main effect of Congruence [W = 110,652, $p < 0.001$, $|r| = 0.26$], wherein participants responded faster in the Congruent blocks [Median = 461 ms, IQR = 88 ms] compared to the Incongruent blocks [Median = 466 ms, IQR = 90 ms]. The analysis also yielded a statistically significant main effect of # of Hands [W = 179,593, p < 0.001, |r| = 0.2], wherein participants responded faster when anticipating Three Hands [Median = 460 ms, IQR = 86 ms] compared to One Hand [Median = 465 ms, IQR = 89 ms]. The interaction effect was also statistically significant [W = 164,850, $p = 0.014$, |

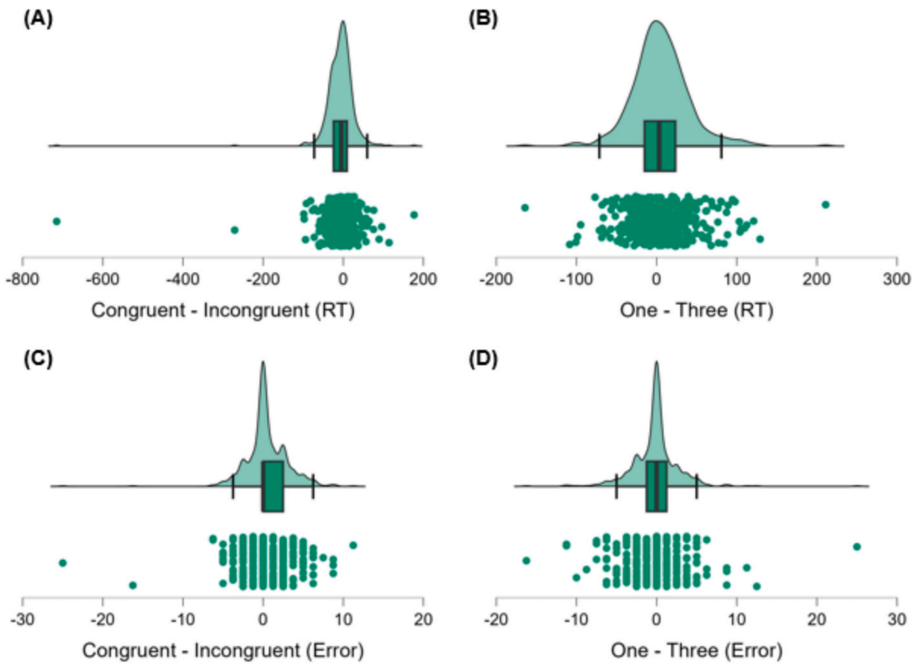

Fig. 8. (A) Raincloud plot of the main effect of Congruence for reaction times. (B) Raincloud plot of the main effect of # of Hands for reaction times. (C) Raincloud plot of the main effect of Congruence for error. (D) Raincloud plot of the main effect of # of Hands for error. Each dot represents a single participant's difference score. To the right are the data represented using boxplots and histogram respectively.

r| = 0.1]. See Fig. 9A and B. Follow-up tests to break down this interaction showed that while there was a significant difference between Congruence in both One Hand condition [W = 112,416, p < 0.001, |r| = 0.25] and Three Hands condition [W = 130,193, *p* = 0.002, |r| = 0.13], this effect seems to be stronger for One Hand over Three Hands.

The Bayesian analysis revealed BF10 = 110,652 for the main effect of Congruence, BF10 = 87 for the main effect of# of Hands, and BF10 = 1.05 for the interaction effect.

5.1.2. *Error rates*

Regarding the Error Rates, the analysis yielded a statistically significant main effect of Congruence [W = 65,514, p < 0.001, |r| = 0.31]

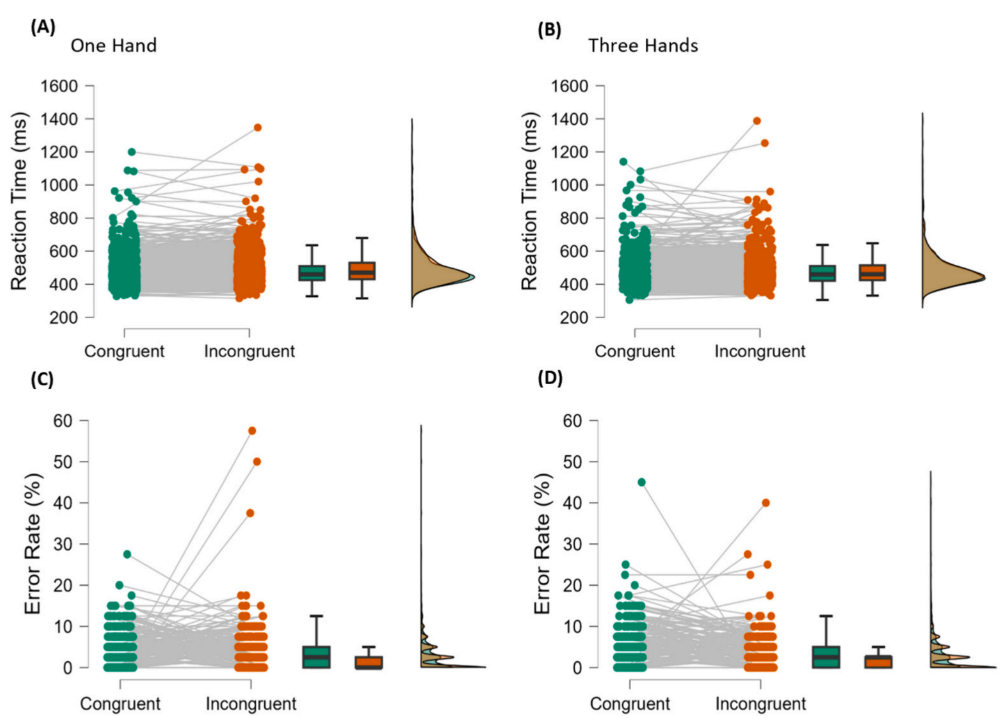

Fig. 9. Raincloud plots of each condition in the combined dataset. (A) and (B) for RT and (C) and (D) for ER data. (A) and (C) for the One Hand condition, and (B) and (D) for the Three Hands condition. Green for congruent trials and orange for incongruent. Each dot represents a single participant, with the line between the dots connecting their scores across conditions. To the right are the data represented using boxplots and histogram respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

wherein participants made more mistakes in the Congruent condition [Median = 2.5%, IQR = 3.8%] compared to Incongruent [[Median = 1.3%, IQR = 3.8%]. The main effect of # of Hands [W = 45,814, p = 0.27, |r| = 0.106] and the interaction [W = 50,457, p = 0.69, |r| = 0.022] were not statistically significant. See Fig. 10C and D.

The Bayesian analysis revealed BF10 = 2754 for the main effect of Congruence, BF10 = 0.09 for the main effect of # of Hands, and BF10 = 0.04 for the interaction effect.

6. General discussion

The aim of this research was to investigate if and how anticipated imitation changes when anticipating multiple agents. To investigate this topic, we had participants make index or middle finger lifts while anticipating either being imitated or counter imitated. Importantly, however, participants either anticipated one or three hands. Based on previous work on the automatic imitation of multiple agents (e.g., Cracco et al., 2015), we expected that participants would be faster when anticipating a congruent finger lift and that this effect would be stronger when anticipating three hands compared to one. Our initial experiment to test this hypothesis did not show evidence for this interaction effect. However, we successfully replicated the classical anticipated imitation effect (faster reaction times for congruent vs. incongruent blocks). Even more interestingly, in experiments 2 and 3, our data pointed to a social facilitation effect such that participants responded faster when anticipating multiple agents compared to just one, *regardless of the type of action* (that is to say, this is a global effect occurring across levels of congruency). This initial finding was reliably replicated in experiment 2 and 3, as well as corroborated by our combined analysis. It has long been established that individual performance during a task can be changed by the mere presence of others (e.g., Bond & Titus, 1983), with results often showing that the presence of others can increase the speed of simple tasks but be detrimental for more complex tasks (although we cannot claim that this effect is specifically a "social" facilitation effect, as non-social stimuli have not been used to compare to in the current set of experiments). This social facilitation effect has also been shown with the automatic imitation of multiple agents (Cracco, Bernardet, et al., 2022). We suggest that anticipating the action of multiple agents has similar effects, such that simply *imagining* future actions from multiple agents is enough to gain this "boost" in motor activity. An interesting future study will be to investigate if this effect is linear or asymptotes after a set number of agents.

While this social facilitation effect is interesting, an important outstanding issue, however, is why this social facilitation effect was not specific for the type of anticipated action (congruent vs. incongruent). As discussed, we initially expected a significant interaction effect. The results, however, were ultimately inconclusive. While we did find statistically significant results of this interaction across the third experiment and the combined analysis, our Bayesian analyses consistently suggested that the data simply could not distinguish between the null and alternative hypotheses. Nevertheless, as the lack of an effect goes against our initial predictions, some speculation on why is warranted.

First, it is interesting to contrast this with work on automatic imitation, which seems to find such an interaction effect consistently. As such, it is possible that while both anticipated and automatic imitation are grounded in ideomotor theory, how shared representations between action and outcome are actually activated between the two may differ sharply in regards to multiple agents – which begs the question of how ideomotor theory can reconcile these findings given it strongly predicts similar effects for both. One possibility, as briefly discussed in section 2.3, is that due to the salient distinction between the two phenomena, such that automatic imitation involves the direct perception of others' actions, while anticipated imitation has one merely imagining future actions, it is possible that imagining multiple actions occurring in the future does not have the same fine-grained effect as directly observing such action, and instead simply increases motor activity of the observer leading to general motor facilitation in the form faster reaction times.

Indeed, the main issue is we cannot say for sure what exactly our participants are imagining when anticipating future actions – is it simply a propositional state (e.g., "The hand(s) will imitate (or not) me")? Or is there a true pictorial image in their mind? (see Bigelow et al. (2023) introduction for a short review on mental imagery research). If the former, then perhaps merely knowing that a proposition to be true is not enough to activate the relevant representations between action and

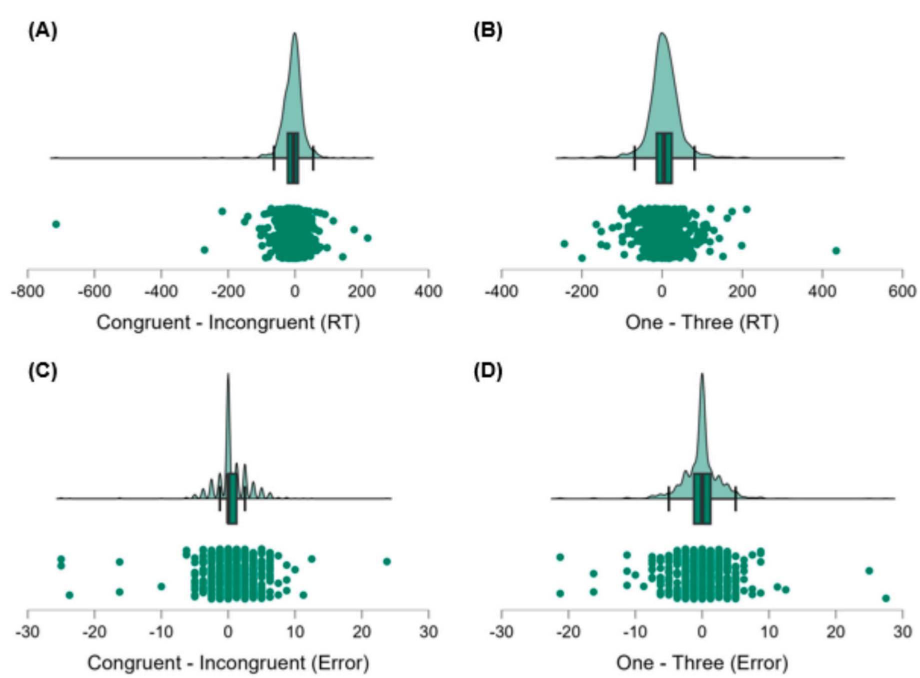

Fig. 10. (A) Raincloud plot of the main effect of Congruence for reaction times. (B) Raincloud plot of the main effect of # of Hands for reaction times. (C) Raincloud plot of the main effect of Congruence for error. (D) Raincloud plot of the main effect of # of Hands for error. Each dot represents a single participant's difference score. To the right are the data represented using boxplots and histogram respectively.

outcome at the level needed for the interaction effect; if the latter, then, at least according to ideomotor theory, we ought to have seen an interaction effect. Furthermore, previous work (see the previously cited papers by Cracco and colleagues above) on the automatic imitation effects of multiple agents have shown that these are effect partially driven by factors like attention or stimuli sampling that may not necessarily work with anticipated imitation of multiple agents. All of this, of course, is highly speculative, especially as we cannot conclusively state that observing multiple agents has no effect on anticipated imitation whatsoever. As such, more work will be needed to truly tease apart differences between automatic and anticipated imitation to reconcile the apparent contradiction stemming from the fact that both effects are related to ideomotor theory.

With all of that said, it is important to note that an alternative possibility is that reaction times are simply not sensitive enough to pick up such effects for anticipated imitation. Work by Rocca and Cavallo (2021) has shown that behavioural kinematics are also influenced by action anticipation effects. As such, an interesting future study will be to investigate if such behavioural kinematics show additive congruency effects when anticipating multiple agents. More direct measures of motor cortical activation may also be better suited at investigating this topic relative to reaction times, as previous work on the automatic imitation of multiple agents have also shown effects at the neural level; e.g., with TMS (Cracco et al., 2016), fMRI (Cracco et al., 2019), and EEG (via frequency tagging; Cracco et al., 2022). Lastly, it is possible that moving away from the use of virtual hand stimuli and using a more social experimental paradigm may be necessary to show additive effects of anticipated imitation of multiple agents (Neszmelyi et al., 2022). One possible limitation of the current study is that we did not have our participants physically in the same room with the imitators as most previous studies have done (e.g., Pfister et al., 2013). However, note that recent (unpublished) work by Neszmelyi and Pfister (2023) also investigated if multiple agents would influence anticipated imitation effects but used a live in-lab setting. Their results generally corroborate what we have found with our online samples: a robust significant effect of Congruence, but no interaction with the number of observed agents. As such, it is unlikely that our use of a fully online sample contributed to the current findings.

In contrast to the two-way interaction effect, but similar to the main effect of # of Hands, we found robust evidence for a main effect of Congruence. Across all three experiments, we successfully replicated the anticipated imitation effect (e.g., Pfister et al., 2013): participants indeed had faster reaction times when anticipating a congruent action relative to incongruent. An interesting point is that the congruence effect is quite tiny across all three online experiments relative to in-person experiments (e.g., with Pfister et al. (2013) originally reporting a strong effect size of $d = 1.26$ compared to the current studies' combined effect size of $d = 0.17$). As such, caution should be heeded such that, at least when using virtual stimuli, large sample sizes will be needed to find the anticipated imitation effect (i.e., the effect is extremely delicate).

It is important to highlight that there are also a number of alternative explanations that could drive parts our of findings. For example, given that Weller et al. (2019) showed that anticipated imitation effects are primarily driven by spatial rather than anatomical compatibility, it is possible that the using a first-person point of view in the current set of experiments may have not been ideal (as there is now an added factor of spatial compatibility not only between the finger movements but also with the different hands moving). Furthermore, the current set of experiments exclusively relied on an allocentric interpretation of left and right (with the reference points being the hands on the screen) and neglects an egocentric interpretation (i.e., left and right relative to the participant). As far as we are aware, no anticipated imitation study has directly investigated egocentric vs. allocentric points of view, and it would be interesting for future work to do so in the context of multiple agents. Relatedly, although experiment 3 controlled for the number of hands perceived in the stimuli, it also created a higher order congruency wherein in one condition all hands moved congruently, but in the other incongruently (i.e., only one of out the three hands made an action). This may explain why participants responded faster in the three-hand condition regardless of action congruency. All-in-all, these possible alternative explanations leave room for future research to further illuminate the nature of multiagent anticipated imitation.

It is also important to note that, unlike previous anticipated imitations study, our experiments did not have a delay between the participants' action and the stimulus response. This may have affected the participants' sense of interaction with the hand(s) stimuli, as having no delay is not plausible in real-life settings (Capozzi et al., 2016). Future research should consider adding quasi-realistic delays to avoid this issue (see: Pfister et al., 2020).

As a final discussion point, in regards to the main effect of Congruence for error rates, we found evidence in experiments 2, 3, and the combined analysis to suggest that participants made slightly more errors when anticipating congruent vs. incongruent actions. Previous work on anticipated imitation has generally not reported statistically significant effects of error rates (e.g., Muller, 2016; Pfister et al., 2013; Weller et al., 2019, 2020). This finding is also in contrast to work on automatic imitation which consistently finds that participants' make *less* errors for congruent vs. incongruent trials. As such, it is difficult to make strong interpretations given both the surprising and counterintuitive nature of this result. One potential issue with this finding is that our reaction time results could be fully explained by an accuracy-speed trade-off. To check if this was indeed an issue, we used a Bayesian Kendall's Tau correlation on the combined dataset correlating the RT effect (Incongruent - Congruent) and the Error Rate effect (Incongruent - Congruent) and found that the data was 3.3 times more likely under the null hypothesis. If our results were indeed fully explained by an accuracy-speed trade-off then we would have expected evidence for a correlation. Nevertheless, future work will be needed to fully elucidate whether this particular finding is theoretically interesting or merely a statistical artifact of the particular stimuli and paradigm used in this study.

To conclude, the current study provided strong evidence for both an anticipated imitation effect (i.e., faster reaction times when anticipating congruent vs. incongruent actions) and a social facilitation effect (i.e., faster reaction times when anticipating three hands vs. one). It did not find evidence that these two effects interact. Nevertheless, we provide some explanations for this null finding as well as compare and contrast our results with that of work on the automatic imitation of multiple agents. We further suggest potential avenues for future research on this topic. Overall, the current results provide the groundwork for further understanding the mechanisms behind multi-agent social interactions.

CRediT authorship contribution statement

Carl Michael Galang: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Emiel Cracco:** Writing – review & editing, Methodology, Conceptualization. **Marcel Brass:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Data availability

I have shared an OSF link in the article containing the data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2024.105831.

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