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The impact of group membership on sensorimotor simulation during social interaction: a focus on embodied prediction of others' movements

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Abstract

Social interaction is fundamental in daily life. While research shows that top-down influences affect social interactions, the level at which this takes place remains unclear. For example, studies investigating the influence of group membership on sensorimotor simulation, a core low-level mechanism of social interaction, have resulted in mixed evidence. We aimed to reconcile and extend these findings to offer a unified account of the effects of group membership on sensorimotor simulation processes. We hypothesized that group membership affects sensorimotor simulation of others' actions only when embodied prediction is necessary. In two experiments, where participants observed hand movements congruent or incongruent with their own, we showed that racial group membership only modulated the congruency effect during response preparation when embodied prediction of the other's movements was present. These results provide insights into how racial group membership, a salient visual inter-individual difference, shapes low-level mechanisms that are fundamental to our social life.

Introduction

Social interaction lies at the core of our daily social life. A growing body of research has investigated how inter-individual differences and top-down influences such as cultural factors affect these social interactions. People tend to identify themselves as members of social groups they belong to (i.e. ingroup), who are perceived as more similar to the self and are differentiated from dissimilar others (i.e. outgroup)[1]. These ingroup versus outgroup classifications are thought to occur spontaneously during social interactions, and affect interpersonal perception and behavior, often leading to ingroup favoritism[2]. One ingroup classification that occurs within milliseconds is race, a particularly visually salient cue of group membership[3]. Racial ingroup members are perceived differently and rated more favorably than racial outgroup members, probably due to differing neural activity[4–6].

A fundamental aspect of human interaction is the automatic tendency to simulate others' sensorimotor states. A growing body of research has investigated how these sensorimotor simulations mechanisms are affected by our interaction partner's group membership, which has resulted in mixed evidence. On the one hand, research shows that high-level cognitive factors, such as the color of the observed person's skin and group membership, influence sensorimotor mirroring of observed neutral actions and emotive states[7–9], empathic sensorimotor and affective mapping of observed painful stimulation[10, 11], neural activation in the human mirror system during intention understanding[12] and imitation[13], and bodily illusions[14–18] and social attention[19]. On the other hand, however, research on the spontaneous imitation of others (automatic imitation), a core low-level sensorimotor mechanism of social interaction, shows conflicting results. The dominant paradigm to study automatic imitation is the *imitation-inhibition paradigm*[20–22]. In this paradigm, participants are asked to make finger lifting movements in response to certain cues (e.g. 'lift index finger when you see the number 1, lift middle finger when you see the number 2'). Irrelevant to the task, a hand on screen simultaneously makes congruent or incongruent movements to the movements that participants are making. The congruency effect (faster reaction times, RTs, on congruent trials and slower RTs on incongruent trials) is taken as

proof of automatic imitation, given that another person's movements automatically impact participants' movements. Studies using the imitation-inhibition paradigm have failed to show a reliable effect of group membership. While some studies have shown stronger imitation of ingroup compared to outgroup members[23, 24], other studies failed to show an influence of group membership[25–28] or even showed a reverse effect[29, 30].

Interestingly, one study, looking at how racial membership modulates online hand kinematics during face-to-face interactions with a virtual avatar, provided evidence for the idea that stronger visuomotor interference emerges when we are required to predict our partner's actions in order to online adapt our own movements accordingly[31]. In this experiment, participants were asked to make reach-to-grasp movements while interacting with avatars that had different skin colors (white versus black) but identical hand kinematics. Caucasian participants were instructed to reach for the lower or upper part of a bottle-shaped object in two conditions. In the Synchrony condition, a tone instructed participants which part of the object they had to reach for, and they were told to synchronize their movements as best as they could with their interaction partner. In the Joint Action condition, a tone informed participants whether they had to perform imitative/congruent or complementary/incongruent synchronous movements compared to their interaction partner. Thus, according to the authors, while participants only had to adapt the timing of their movements in the Synchrony condition, the Joint Action condition required participants to both synchronize and online select their action goal according to their partner's movements, which led to stronger visuomotor interference (i.e. an influence of the other person's actions on their own). Importantly, visuomotor interference was also stronger when interacting with the ingroup compared to the outgroup partner, indicating that racial membership affects predictive embodied simulation of the interaction partner's movements and that the impact of group membership on sensorimotor simulation is linked to action prediction. While the authors recognize that the absence of visuomotor interference during interactions with outgroup members is reminiscent of the modulation exerted by racial bias on mirror-like responses in others' actions and pain observation[7–11], their findings suggest that visuomotor interference and its modulation by group membership only arises when participants need to predict their partner's movements in order to adapt to them. Interestingly, the authors only observed this effect for precision grip kinematics, arguing that this type of grip is sensitive to the cognitive and social context in which actions are performed[32–37], possibly due to its complex cortical organization needed to control its execution[38–41]. This study raises the question of 1) whether the absence of a reliable effect of group membership in the imitation-inhibition paradigm, which is also thought to investigate the automatic interference of others' actions on our own, is due to the low complexity of the movements (i.e. finger lifting movements) used within this paradigm or 2) whether the original imitation-inhibition paradigm doesn't allow for predictive embodied sensorimotor simulation processes that the authors in[31] propose as the driving force behind effects of group membership. The reconciliation of these findings is important to validate the findings of[31] and to offer a unified account of the effects of group membership on low-level sensorimotor simulation mechanisms that form the basis of our everyday interactions.

In the current study, we aimed to reconcile and extend the above findings of[31], who observed effects of racial group membership on visuomotor interference during reach-to-grasp movements (precision grips), with research using the imitation-inhibition task that has failed to observe such interactions on RTs and error rates using less complex movements. In Experiment 1, we adapted the paradigm as described in[31] to an RT paradigm to 1) investigate the influence of race on finger lifting movements, and thus open up this paradigm to examine less complex actions (compared to precision grips) and their sensitivity to the cognitive and social context in which they are performed, and 2) directly link the paradigm of[31] to the imitation-inhibition paradigm which has failed to show a reliable effect of racial group membership on sensorimotor simulation and to investigate whether this is due to the absence of embodied predictive simulation processes in the original paradigm. More specifically, we aimed to investigate whether the congruency effect of the imitation-inhibition paradigm was only modulated by group membership when participants were required to truly simulate and predict the observed person's actions (i.e. when visuomotor interference was present). Furthermore, we tested both white and black participants (with both groups observing both white and black hands), to investigate whether the findings of[31] were generalizable across populations with different ethnic backgrounds (see Fig. 1 for experimental setup).

Experiment 2, we aimed to explore the role of response preparation versus execution. More specifically we investigated 1) whether response preparation-execution overlap was responsible for the effects found in Experiment 1 compared to the unique role of visuomotor interference, and 2) during which phase of the motor response (preparation versus execution) race plays a modulatory role. Neural findings have suggested, for example, that ethnicity does not affect motor execution during automatic imitation[42]. The findings of both experiments were expected to provide crucial insights into the influence of race – one of the visually most salient inter-individual differences[43, 44] – on sensorimotor simulation, a mechanism that lies at the core of our everyday social interactions.

Experiment 1

Results

Congruency does not interact with Observed Race in Non-Joint Action blocks

For Non-Joint Action blocks, a main effect of Congruency was observed, $F(1,65) = 117.76$, $p < .001$, $\eta^2 = .140$ as well as a main effect of Participant Race, $F(1,65) = 6.05$, $p = .017$, $\eta^2 = .073$. Additionally, a significant interaction effect between Congruency and Participant Race was also found, $F(1,65) = 8.35$, $p = .005$, $\eta^2 = .011$ (see Figure 2A). Follow-up tests revealed that there were no differences between White ($M = 453.27$, $SD = 44.61$) and Black ($M = 469.19$, $SD = 45.06$) participants for Incongruent trials ($t(65) = 1.45$, $p = .151$). For Congruent trials, however, Black participants reacted significantly slower ($M = 442.12$, $SD = 50.13$) than White participants ($M = 406.55$, $SD = 39.58$; $t(65) = 3.22$, $p = .002$, $d = .79$).

Congruency, Observed Race, and Participant Race interact in Joint Action blocks

For Joint Action blocks, main effects were observed for Congruency, $F(1,72) = 4.72$, $p = .033$, $\eta^2 = .002$, Observed Race, $F(1,72) = 24.01$, $p < .001$, $\eta^2 = .006$, and Participant Race, $F(1,72) = 6.76$, $p = .011$, $\eta^2 = .073$. Furthermore, significant interaction effects between Congruency and Observed Race, $F(1,72) = 31.26$, $p < .001$, $\eta^2 = .049$, as well as Observed Race and Participant Race, $F(1,72) = 5.32$, $p = .024$, $\eta^2 = .001$, were found. Importantly, a three-way interaction between Congruency, Observed Race, and Participant Race was also observed, $F(1,72) = 256.09$, $p < .001$, $\eta^2 = .297$ (see Figure 2B). For White participants, Incongruent trials ($M = 514.71$, $SD = 47.27$) were significantly slower than Congruent trials ($M = 479.31$, $SD = 40.15$) when observing White hands ($t(34) = -3.78$, $p < .001$, $d = -.64$), while the reverse (slower RTs for Congruent, $M = 526.47$, $SD = 45.37$, compared to Incongruent, $M = 488.09$, $SD = 43.10$, trials) was true when observing Black hands ($t(34) = 6.39$, $p < .001$, $d = 1.08$). For Black participants, the reverse pattern was observed. More specifically, when observing Black hands, slower RTs for Incongruent ($M = 563.64$, $SD = 45.29$) compared to Congruent ($M = 493.19$, $SD = 45.22$) trials were found ($t(38) = -24.89$, $p < .001$, $d = -3.99$). For White hands, Congruent trials ($M = 566.01$, $SD = 42.07$) were significantly slower than Incongruent trials ($M = 483.43$, $SD = 44.53$; $t(38) = 39.85$, $p < .001$, $d = 6.38$).

Discussion

In Experiment 1, we investigated the influence of group membership on visuomotor interference during social interactions. White and black participants performed a task that consisted of two task conditions: a Non-Joint Action and a Joint Action condition. In both conditions, participants were asked to make finger lifting movements in response to colored circle cues, while the hand of a white or black person on screen made congruent or incongruent movements. Importantly, we hypothesized that only in the Joint Action condition participants were required to truly simulate and predict the other's action, and that only when such visuomotor interference was present would group membership of the observed hand modulate the congruency effect[31].

The results of Experiment 1 showed that a traditional congruency effect (faster RTs on congruent and slower RTs on incongruent trials) was observed in Non-Joint Action blocks, irrespective of the race of the observed hand. For Joint Action blocks, however, a reversed congruency effect was observed when the observed race was different than the participants' race (i.e. white participants showed a reversed congruency effect when observing black hands, while black participants showed a reversed effect for white hands). Thus, only when visuomotor interference was required to perform the task (i.e. when participants were required to truly simulate and predict the other person's actions) did the race of the observed other influence participants' movement times.

Importantly, the Non-Joint Action and Joint Action blocks differed in the timing of response preparation and execution. In Non-Joint Action blocks, where the circle cue informed participants about the specific movement they had to make, participants were able to prepare their response as soon as this cue appeared. Then, after 1000 ms, they had to execute this response as synchronously as possible with the observed hand. Thus, in Non-Joint Action blocks, response preparation and execution were separated, and participants were able to prepare their response beforehand. In Joint Action blocks, on the other

hand, the circle cue did not inform participants about the exact movement they had to make. The cue merely informed participants whether they had to make the same or the opposite movement to the movement that the hand on screen would perform. Thus, participants had to wait until the hand on screen made its movement before planning and executing their movements immediately. This raises two important questions: 1) Is the interaction effect between Congruency and Observed Race in Joint Action blocks the result of visuomotor interference or does the effect arise because of the overlap between response preparation and execution in these blocks?; 2) If the interaction between Congruency and Observed Race is not merely caused by response preparation-execution overlap, does it arise during the response preparation or execution phase?

Based on previous research using the imitation-inhibition task[21], we predicted that overlap between response preparation and execution alone would not explain the effects observed in Experiment 1. In the imitation-inhibition task, the response cue is presented at the same time as the movement of the observed hand on screen, and response preparation-execution overlap is complete. However, effects of group membership on the congruency effect in this task have not been observed when looking at behavioral measures[26–28]. Furthermore, research using event-related potentials (ERPs) has shown that ethnicity does not influence motor execution during tasks that require motor simulation[42]. Thus, we predicted that the effect of group membership on visuomotor interference arises during response preparation.

In order to test this, we adapted the paradigm as developed in Experiment 1. More specifically, in Experiment 2, we first presented a frame that showed participants both the color circle cue as well as the observed hand's movement for both task conditions. This way, both in Non-Joint Action and Joint Action blocks, participants were able to prepare their response immediately. Participants were then told that they had to wait for a sound cue which would inform them of when they were allowed to make their movement (movement execution). This sound cue was presented at 0 ms, 300 ms, or 600 ms stimulus-onset asynchrony (SOA). At 0 ms, response preparation-execution overlap is present in both conditions, allowing us to answer the first question that was prompted by the results of Experiment 1 ("Is the interaction effect between Congruency and Observed Race in Joint Action blocks the result of visuomotor interference or does the effect arise because of the overlap between response preparation and execution in these blocks?"). The second question ("If the interaction between Congruency and Observed Race is not merely caused by response preparation-execution overlap, does it arise during the response preparation or execution phase?") was examined by investigating whether the interaction between Congruency and Observed Race was present at 300 ms (response preparation still in progress) and/or 600 ms (response preparation largely resolved) SOA[21,29,45,46] (see Figure 3 for experimental setup).

Experiment 2

Results

Congruency, Observed Race, and SOA do not interact in Non-Joint Action blocks

For Non-Joint Action blocks, main effects of Congruency, $F(1,35) = 881.93$, $p < .001$, $\eta^2 = .417$, and Observed Race, $F(1,35) = 8.28$, $p = .007$, $\eta^2 = .005$, were observed. Furthermore, significant interactions were found between Congruency and SOA, $F(2,70) = 22.10$, $p < .001$, $\eta^2 = .050$, as well as between Observed Race and SOA, $F(2,70) = 10.80$, $p < .001$, $\eta^2 = .009$ (see Figure 4A). Follow-up tests showed that the Congruency effect was bigger for 0 ms SOA (Congruent: $M = 477.56$, $SD = 92.56$; Incongruent: $M = 706.28$, $SD = 93.36$; $t(35) = -18.32$, $p < .001$, $d = -3.05$) compared to 300 ms (Congruent: $M = 502.38$, $SD = 76.16$; Incongruent: $M = 670.14$, $SD = 101.14$; $t(35) = -20.75$, $p < .001$, $d = -3.46$) and 600 ms (Congruent: $M = 507.74$, $SD = 138.71$; Incongruent: $M = 619.89$, $SD = 97.54$; $t(35) = -8.27$, $p < .001$, $d = -1.38$) SOA. Furthermore, for 600 ms SOA participants reacted faster to observing Black hands ($M = 545.02$, $SD = 127.68$) compared to White hands ($M = 582.60$, $SD = 134.59$, $t(35) = -5.27$, $p < .001$, $d = -.88$), while no differences were found for 0 (White hands: $M = 598.80$, $SD = 149.55$; Black hands: $M = 585.05$, $SD = 146.11$; $t(35) = -1.80$, $p = .080$, $d = -.30$) and 300 ms (White hands: $M = 581.75$, $SD = 126.26$; Black hands: $M = 590.77$, $SD = 119.66$; $t(35) = 1.13$, $p = .266$, $d = .19$) SOA.

Congruency interacts with Observed Race for short SOAs in Joint Action blocks

For Joint Action blocks, main effects of Congruency, $F(1,30) = 197.05$, $p < .001$, $\eta^2 = .131$, Observed Race, $F(1,30) = 116.93$, $p < .001$, $\eta^2 = .058$, and SOA, $F(2,60) = 75.75$, $p < .001$, $\eta^2 = .426$, were found. Significant interactions between Congruency and Observed Race, $F(1,30) = 1411.18$, $p < .001$, $\eta^2 = .564$, Congruency and SOA, $F(2,60) = 43.28$, $p < .001$, $\eta^2 = .108$, and Observed Race and SOA, $F(2,60) = 128.24$, $p < .001$, $\eta^2 = .191$, were present as well. Importantly, a significant three-way interaction between Congruency, Observed Race, and SOA, $F(2,60) = 174.65$, $p < .001$, $\eta^2 = .324$, was also observed (see Figure 4B). For 0 ms SOA, when observing White hands, participants were faster on Congruent ($M = 511.78$, $SD = 82.67$) compared to Incongruent ($M = 727.43$, $SD = 60.81$, $t(30) = -12.69$, $p < .001$, $d = -2.28$) trials, while the reverse was true when observing Black hands (Congruent: $M = 739.08$, $SD = 104.45$; Incongruent: $M = 507.02$, $SD = 89.24$; $t(30) = 14.37$, $p < .001$, $d = 2.58$). The same was true for 300 ms SOA, where faster RTs were observed for Congruent ($M = 403.58$, $SD = 79.83$) compared to Incongruent ($M = 753.09$, $SD = 125.67$) trials when observing White hands ($t(30) = -22.37$, $p < .001$, $d = -4.02$), but where slower RTs were observed for Congruent ($M = 655.78$, $SD = 87.04$) compared to Incongruent ($M = 437.49$, $SD = 90.67$) trials when observing Black hands ($t(30) = 22.38$, $p < .001$, $d = 4.02$). Importantly, for 600 ms SOA, participants were faster on Congruent compared to Incongruent trials both when observing White (Congruent: $M = 307.84$, $SD = 52.08$; Incongruent: $M = 462.11$, $SD = 41.32$; $t(30) = -13.30$, $p < .001$, $d = -2.39$) and Black (Congruent: $M = 481.58$, $SD = 52.36$; Incongruent: $M = 578.54$, $SD = 46.28$; $t(30) = -13.83$, $p < .001$, $d = -2.48$) hands.

Discussion

In Experiment 2, we sought to provide answers to two research questions. First, like in

Experiment 1, we only observed an interaction between Congruency and Observed Race in Joint Action blocks. Given that we hypothesized that 0 ms resulted in a complete overlap between response preparation and execution and that this did not result in an interaction between Congruency and Observed Race in Non-Joint Action blocks, this provides evidence for the idea that the effect of group membership on the congruency effect is not explained by mere overlap between response preparation and execution. Furthermore, the three-way interaction between Congruency, Observed Race, and SOA in Joint Action blocks provided evidence for the idea that the effect of group membership arises during the response preparation phase instead of during response execution. More specifically, while the interaction between Congruency and Observed Race was present at 0 and 300 ms SOA, it was no longer present at 600 ms SOA (when response preparation was thought to be largely resolved).

General discussion

In a series of two experiments, we investigated the influence of racial group membership

on sensorimotor simulation. A growing body of research has investigated how inter-individual differences influence our perception and behavior, but research looking at the influence of race on sensorimotor simulation – a core low-level mechanism of social behavior[47] – has resulted in mixed findings. While various studies have shown that group membership affects several processes important for interactive behavior[7–15,19], research looking at automatic imitation has failed to observe such effects[25–30].

In a first experiment, we adapted the paradigm as described in[31]. In this study, the authors demonstrated an effect of racial group membership on hand kinematics during face-to-face motor interactions with virtual interaction partners. In particular, they showed that a modulation of visuomotor interference by race only occurs when participants need to predict others' movements in order to adapt to them. Using an adaptation of the imitation-inhibition paradigm, we replicated and extended these findings, showing that the effects of[31] were replicable using RTs of less complex movements and that the absence of embodied predictive simulation in the original imitation-inhibition paradigm might be responsible for the failure to observe racial group modulations thus far. More specifically, we showed that an interaction between race of the observed person and the congruency effect (slower RTs when own finger lifting movements and observed person's movements are incongruent, faster RTs when movements are congruent) was only observed in Joint Action blocks, where visuomotor interference and embodied predictive simulation were thought to be stronger given that participants were asked to adjust their movements to the movements of the observed person. More specifically, we found a congruency effect when the race of the observed person and the participant's race was congruent, while a reverse congruency effect was observed when both races were incongruent. This was observed for both white and black participants, indicating that the results of this experiment were generalizable across different ethnic groups. Importantly, the results of Experiment 1 reconcile findings that were previously thought to be contradictory, helping to form a unified framework concerning the effects of group membership on low-level sensorimotor processes and shedding light on the underlying mechanisms (i.e. embodied

predictive simulation). Thus, while the results of Experiment 1 replicate the research in[31], they are also in line with research on automatic imitation, largely showing no effects of group membership[25–28], given that our Non-Joint Action condition replicated the classic imitation-inhibition paradigm. This seems to suggest that an effect of race doesn't necessarily occur automatically during motor interactions, but might be susceptible to other factors being present (i.e. the need to predict and adapt to the other person's movements). This is in line with the few studies that have found a modulatory role of group membership on automatic imitation, which only found this effect when there was a high motivation to affiliate with the ingroup[23,24] (but see[26] for contradictory findings) or found a reverse effect when emotional valence was manipulated[29,30]. Interestingly, social-psychological research in more natural settings has consistently found that ingroup members are mimicked more than outgroup members[48–53]. This might suggest that effects of group membership only emerge in natural and more ecologically valid contexts (e.g. more natural movements), although research has pointed out that automatic imitation and motor mimicry do not correlate and therefore probably measure (at least partially) different processes[54]. Furthermore, these studies have used relatively small samples, while studies looking at group membership effects in the imitation-inhibition paradigm have employed large samples to demonstrate the absence of any effects[27].

Another important difference between the Non-Joint Action and Joint Action blocks in Experiment 1 was the timing of response preparation and execution. In Non-Joint Action blocks, participants were informed of the exact movement that had to be executed immediately, and were thus able to prepare their response before it had to be executed. In Joint Action blocks, however, participants were not able to prepare their movements beforehand, which caused an overlap between response preparation and execution. To rule out that this confound was responsible for the influence of race on the congruency effect in Join Action blocks, we conducted a follow-up experiment. This experiment, which aimed to disentangle response preparation and execution, showed that 1) response preparation-execution overlap was likely not responsible for the modulatory role of group membership in Joint Action blocks, and 2) the effect of group membership arises (at least partly) during the response preparation phase. The former is again in line with research using the classic imitation-inhibition paradigm (where response preparation and execution overlap was present[26–28]), while the latter is reminiscent of psychophysiological findings on motor simulation showing that ethnicity does not influence motor execution[42]. The latter study, looking at the temporal processes underlying automatic imitation and its modulation by ethnicity, showed that stimulus categorization of race is reflected in ERPs during early stages of stimulus processing, but not ERPs during movement execution or overt behavioral responses immediately before and after the execution. Furthermore, another study by the same authors showed that while behavioral responses during automatic imitation are not influenced by group membership, response-locked ERPs reflecting conflict monitoring/action control are influenced by social context manipulations[55]. Our results extend these findings by showing that behavioral measures of sensorimotor simulation are affected by racial group membership during the response preparation phase, but not execution phase only when participants are required to simulate and adapt to others' movements.

Our experiments have several limitations. First, while we found an effect of embodied prediction when investigating the effects of racial group membership on sensorimotor simulation, it remains to be investigated whether the same holds true for other forms of group membership. For example, gender is another inter-individual difference that is often, though not always, visually salient. While we did not observe any interactions with gender in the current study, a thorough investigation of gender effects is warranted. Furthermore, in contrast to other studies, we did not use artificial groups or minimal group paradigms to manipulate group membership, which could lead to different effects. Finally, aside from group membership, we did not investigate other moderators that could influence the effect of embodied prediction on sensorimotor simulation and its interaction with race, such as attention[26], motivation to affiliate[23,26], cooperation versus competition[24] and emotional valence[29,30].

Second, while – as mentioned in the general discussion – it has been shown that automatic imitation and mimicry do not correlate[54], it remains unclear why studies looking at mimicry have consistently found effects of group membership[48–53] in contrast to automatic imitation studies. Again, the impact of embodied prediction in these more ecologically valid settings, and the link with sensorimotor simulation processes, needs to be further investigated.

Finally, our paradigm offers a straightforward way to look at overt behavioral indices of the influence of group membership on sensorimotor simulation during social interactions. This is important, given that most studies looking at effects of group membership and how they can be altered, for example using bodily illusions and/or virtual reality applications, typically use implicit measures[14,15,18,60–62] (e.g. the implicit association test[63,64]). However, the relationship between these implicit measures of racial bias and explicit, overt behavior remains unclear[65], making it difficult to infer the behavioral impact of interventions that aim to counteract racial bias. While our study offers a tentative starting point, future studies should further investigate the link between our explicit behavioral measure and implicit measures of racial bias, as well as more complex, explicit higher-level behavior. This would allow for a more thorough investigation of how explicit and implicit measures of racial bias can be used to study behavioral changes following interventions.

In conclusion, in a series of two experiments we showed that group membership affects sensorimotor simulation only when visuomotor interference and embodied prediction of others' movements is necessary for successful motor interaction. This provides important insights into the extent of the influence of group membership on low-level core mechanisms that are fundamental to our everyday social life and (socially biased) interactions. Furthermore, these results also question motivational theories that postulate that we automatically imitate ingroup members more than outgroup members[56], instead indicating that a close link between motor simulation and action prediction in interactive contexts might be fundamental for inter-individual differences to play a role[57–59]. Finally, our findings indicate that these mechanisms might be especially important during response preparation phases.

Methods

Experiment 1

Participants

In Experiment 1, we tested both black and white participants. Sample size for each group (n = 40) was determined based on previous work using the imitation-inhibition paradigm[26,60] and on a power analysis showing that such a sample provided 80% power to detect relatively medium-sized effects (d = .45). Group membership was assessed by asking participants to indicate their ethnic background at the end of the study. As soon as the desired sample size was reached for a particular group, recruitment for this group was terminated. Gender was assessed by asking participants how they would describe their gender including the following options: Male (including transgender men), Female (including transgender women), Prefer to self-describe as (non-binary, gender-fluid, agender, please specify), Prefer not to say.

40 participants participated in each group (Black participants: M_{age} = 33.25, SD = 9.57, Gender: 17 Female, 21 Male, 2 Non-binary; White participants: M_{age} = 35.05, SD = 11.23, Gender: 20 Female, 18 Male, 1 Non-binary, 1 Prefer not to say). Participants were recruited through university mailing lists and online advertisements. Both studies were conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and were granted ethical approval by the local ethics committee at Universidad Carlos III de Madrid (approval ID: PICONEX_LETO). All participants provided informed written consent before participating.

Stimuli and apparatus

Data was collected online using jsPsych[61] and JATOS[62]. The online imitation-inhibition paradigm was adapted from[63]. The minimum screen size was set at 1280 x 700 to ensure that the task was performed using a large enough computer screen. Participants were instructed to finish the task in one go. As such, participants were not able to open the experiment link more than once, and participants' whose task duration exceeded 45 min were excluded from further analyses.

As in the classic imitation-inhibition task, the main task of participants consisted of making finger lifting movements by releasing the G key (to lift the index finger) or H key (to lift the middle finger) of their keyboard in response to certain cues, while being asked to otherwise hold down the G and H keys at all times. At the same time, participants were presented with frames of black and white hands on their computer screens (625 x 459 px). These frames were adapted from[27], where black and white hands were created using computer software to control for potential confounds such as shape or size of the hand, or the kinematics of the finger movements.

The experiment consisted of two different task conditions, each consisting of a presentation of two stimulus frames: in Non-Joint Action blocks, a purple or blue circle was presented in between the index and middle finger of the hand on screen (in resting position; first stimulus frame), to indicate to participants that their index or middle finger had to be lifted, respectively. In Joint Action blocks, a yellow (lift same finger as the hand on screen) or orange (lift opposite finger as the hand on screen) circle was

presented in between the observed resting hand's index and middle fingers. Importantly, in both task conditions, participants were instructed to make their finger lifting movements as synchronously as possible with the finger movements of the hand on screen (second stimulus frame), which could be congruent or incongruent with their own movements.

The experiment consisted of two within-subject factors: Congruency (Congruent vs Incongruent) and Observed Race (White vs Black). Participant Race (White vs Black) acted as a between-subjects factor. Tasks condition (Non-Joint Action vs Joint Action) was manipulated within subjects, but both blocks were analyzed separately.

Procedure

Participants were sent a link to perform the study online, and were first asked to provide informed consent, with the possibility of contacting the experimenter for more information and questions. Afterwards, participants were given a set of instructions, which they could scroll through at their own pace.

Participants were presented with two practice blocks: a Non-Joint Action and a Joint Action block (randomized). Each block consisted of 24 randomized trials, during which participants observed an equal amount of purple/blue or yellow/orange circle cues. For each cue type, each trial type (congruent movement – white hand, incongruent movement – white hand, congruent movement – black hand, incongruent movement – black hand) was again presented an equal amount of times. A single trial was designed as follows (see Figure 1): first, a fixation cross was presented for 500 ms. Second, participants observed a resting hand on screen, together with the circle cue for 1000 ms. Third, the frame of the hand making a finger movement (lifting index or middle finger) was presented. During the presentation of this frame, participants were instructed to respond by lifting their index or middle finger (according to the cue presented earlier) as fast and accurately as possible, with a maximum response time of 2000 ms. If no response was given within this 2000 ms window, the trial was counted as incorrect. During the practice blocks, participants were presented with feedback on the accuracy of their response for 500 ms. Finally, an inter-trial interval was presented for 1000 ms before the next trial started.

After going through the two practice blocks, participants performed four experimental blocks (pseudorandomized, with no consecutive blocks of the same type): two Non-Joint Action and two Joint Action blocks. Each block was designed as the practice blocks, with the exception that each block consisted of 40 trials, resulting in a total amount of 160 experimental trials. Furthermore, during the experimental blocks, no feedback on the accuracy of their response was given to participants. The total experiment had an approximate duration of 15 min.

Hypotheses

In Experiment 1, we aimed to replicate previous research[31]. Given that a meta-analysis demonstrated that effects are usually more robust when looking at RTs compared to accuracy[21], we focused our

investigation on the former.

First, we hypothesized that a main effect of Congruency (slower RTs for incongruent trials, faster RTs for congruent trials) would be present, regardless of the task condition. Second, we predicted that an interaction effect between Congruency and Observed Race would be present only when participants were required to simulate and predict the observed person's actions (i.e. in the Joint Action blocks). Furthermore, we hypothesized that this effect would interact with Participant Race (i.e. three-way interaction between Congruency, Observed Race, and Participant Race). More specifically, for White participants, we predicted that the Congruency effect would only be present when observing the white hand on screen, while no (or possible a reversed Congruency effect) would be present when presented with the black hand on screen. The reverse was predicted for Black participants.

Analysis

RT results were analyzed in R[64] using a 2 (Congruency: Congruent vs Incongruent) x 2 (Observed Race: White vs Black) x 2 (Participant Race: White vs Black) Analysis of variance (ANOVA) for Non-Joint Action and Joint Action blocks separately. Follow-up paired *t*-tests were corrected for multiple comparisons using Bonferroni correction. To assess significance, alpha was set to $p < .05$. Participants were excluded from the analyses if their mean RT exceeded the sample mean by ≥ 3 *SD*. Trials were excluded if they were not answered correctly (including not answering within the time limit of 2000 ms) or if the RT was < 100 ms. Interactions with Gender were analyzed, but none were observed.

Experiment 2

Participants

Given that Experiment 1 demonstrated that black participants showed the reversed pattern compared to white participants and that the results were generalizable across ethnic populations, we limited Experiment 2 to white participants only. Participants' gender was assessed as in Experiment 1. 40 participants (M_{age} = 31.79, *SD* = 9.25, Gender: 18 Female, 19 Male, 2 Non-binary, 1 Genderfluid) participated in the study. They were recruited via university mailing lists and online advertisements. Participants who had participated in Experiment 1 were excluded from participating in this follow-up study.

Stimuli and apparatus

Stimuli were largely the same as the stimuli used in Experiment 1, consisting of two frames that were presented in successive order. In the first frame, a resting white or black hand was presented to participants. In a second frame, the circle cue (purple/blue or yellow/orange) was presented while the observed hand (white or black) was lifting their index or middle finger. While this circle cue informed participants about *which* movement they had to make, a short sound (duration: .15 sec, frequency: 1002.57 Hz) notified participants about *when* they had to make the movement. This sound was presented either at the same time as the cue-movement frame (0 ms SOA), or 300 ms or 600 ms after

the presentation of this frame had started. As in Experiment 1, the hand on screen made a congruent or incongruent movement compared to the movement that participants had to perform.

The experiment consisted of three within-subject factors: Congruency (Congruent vs Incongruent), Observed Race (White vs Black), and SOA (0 vs 300 vs 600 ms). Again, task condition was manipulated within subjects, but Non-Joint Action and Joint Action blocks were analyzed separately.

Procedure

As in Experiment 1, participants were sent a link to perform the study online. They provided informed written consent and were presented with a set of self-paced instructions. To start, participants were informed that they would hear short sounds during the experiment. First, participants were asked to turn on the sound of their laptop or computer, and to plug in any headphones that they had available. Then, they were informed that they would hear a short sound ten times after pressing ENTER, and that they should adjust the sound to a comfortable level. After this adjustment phase (which they could repeat if necessary), instructions for the experimental task were presented.

As in Experiment 1, participants first went through two randomized practice blocks: one Non-Joint Action, and one Joint Action block. Each block consisted of 24 randomized trials, during which participants observed an equal amount of purple/blue or yellow/orange circle cues. For each cue type, each trial type (congruent movement – white hand, incongruent movement – white hand, congruent movement – black hand, incongruent movement – black hand) was combined once with each SOA type (0 ms – 300 ms – 600 ms). A single trial was designed as follows (see Figure 3): first, a fixation screen, consisting of a frame of the resting hand, was presented for 500 ms. Second, participants were presented with the cue-movement frame where the circle cue was presented together with the hand on screen making an index or middle finger lifting movement. After 0 ms, 300 ms, or 600 ms, the short sound was presented for 175 ms. After the presentation of this sound, participants were asked to make the appropriate finger lifting movement as fast and accurately as possible. If no response was given within a 2000 ms window or if the movement was performed too early (i.e. during the presentation of the sound), the response was counted as incorrect. During these practice blocks, participants were presented with feedback on the accuracy of their movement for 500 ms. Finally, after an inter-trial interval of 1000 ms, the next trial started.

Following the two practice blocks, participants observed four experimental blocks (pseudorandomized, with no consecutive blocks of the same type): two Non-Joint Action, and two Joint Action blocks. Each block was designed as the practice blocks, with the exception that each trial type was presented with each SOA type three times, resulting in 72 trials per block, and a total amount of 288 trials. Unlike during the practice blocks, no feedback on the accuracy of their responses was given to participants. The total experiment had an approximate duration of 15 min.

Hypotheses

Experiment 2 was developed to investigate two main questions. First, we aimed to examine the role of overlap between response preparation and execution as a possible confound for the effects observed in Experiment 1. Importantly, in Experiment 2, response preparation was possible as soon as the cue-movement frame appeared for both the Non-Joint Action and Joint-Action blocks, while execution depended on the beep sound at 0, 300, or 600 ms. Given that we hypothesized that the overlap between response preparation and execution did not explain the effects, we expected to only observe an interaction between Congruency and Observed Race in the Joint Action blocks. Conversely, if the response preparation-execution overlap partially explained the results observed in Experiment 1, an interaction between Congruency and Observed Race should be present at 0 ms SOA, where the overlap between response preparation and execution is complete, for both task conditions (i.e. both in Non-Joint Action and Joint Action blocks).

Second, we wanted to investigate whether the interaction effect between Congruency and Observed Race in Joint Action blocks arises during response preparation or execution. If this effect originates during the response preparation phase, we expected that longer SOAs (particularly 600 ms SOA) should reduce or eliminate this interaction effect (i.e. three-way interaction between Congruency, Observed Race, and SOA), given that longer SOAs allow for more time to resolve any conflict and for the response preparation phase to be largely finished[65–67]. If, however, longer SOAs did not alter this interaction effect (i.e. no three-way interaction between Congruency, Observed Race, and SOA), this would provide evidence for the idea that the effect is (at least partially) initiated during the response execution phase.

Analysis

For Non-Joint Action and Joint Action blocks, results were analyzed using a 2 (Congruency: Congruent vs Incongruent) x 2 (Observed Race: White vs Black) x 3 (SOA: 0 ms vs 300 ms vs 600 ms) ANOVA. Follow-up *t*-tests were corrected for multiple comparisons using Bonferroni correction. To assess significance, alpha was set to $p < .05$. Participant and trial exclusion followed the criteria as outlined in Experiment 1. Interactions with Gender were analyzed, but none were observed.

Declarations

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Author contributions

Conceptualization, L.D.C., A.T.J., and B.S.; Methodology, L.D.C.; Formal Analysis, L.D.C.; Investigation, L.D.C.; Data curation, L.D.C.; Writing – Original Draft, L.D.C.; Writing – Review and Editing, L.D.C., A.T.J., and B.S.; Visualization, L.D.C.; Supervision, A.T.J. and B.S.; Funding Acquisition, L.D.C., A.T.J., and B.S.

Data availability

All data and analysis materials are publicly available: https://osf.io/cfy75/overview?view_only=e800f1a38d2a456fa9341c1425e01414

Competing interests

The authors declare no competing interests.

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Figures

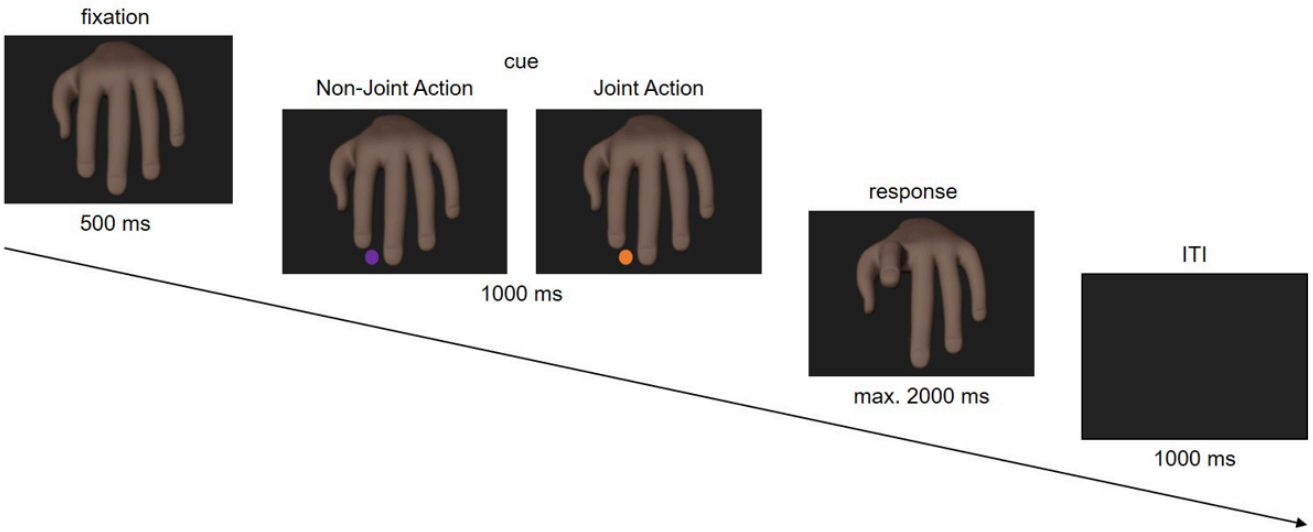


Figure 1

Experimental setup Experiment 1. Participants were asked to make finger lifting movements in response to certain cues, and to synchronize their movements with the movements of the hand on screen. In Non-Joint Action blocks, a purple (lift index finger) or blue (lift middle finger) circle was presented. In Joint Action blocks, where embodied prediction was necessary to perform the task, a yellow (lift same finger as hand on screen) or orange (lift opposite finger as hand on screen) circle was presented. In both blocks, the observed hand's movement could be congruent or incongruent with participants' movements.

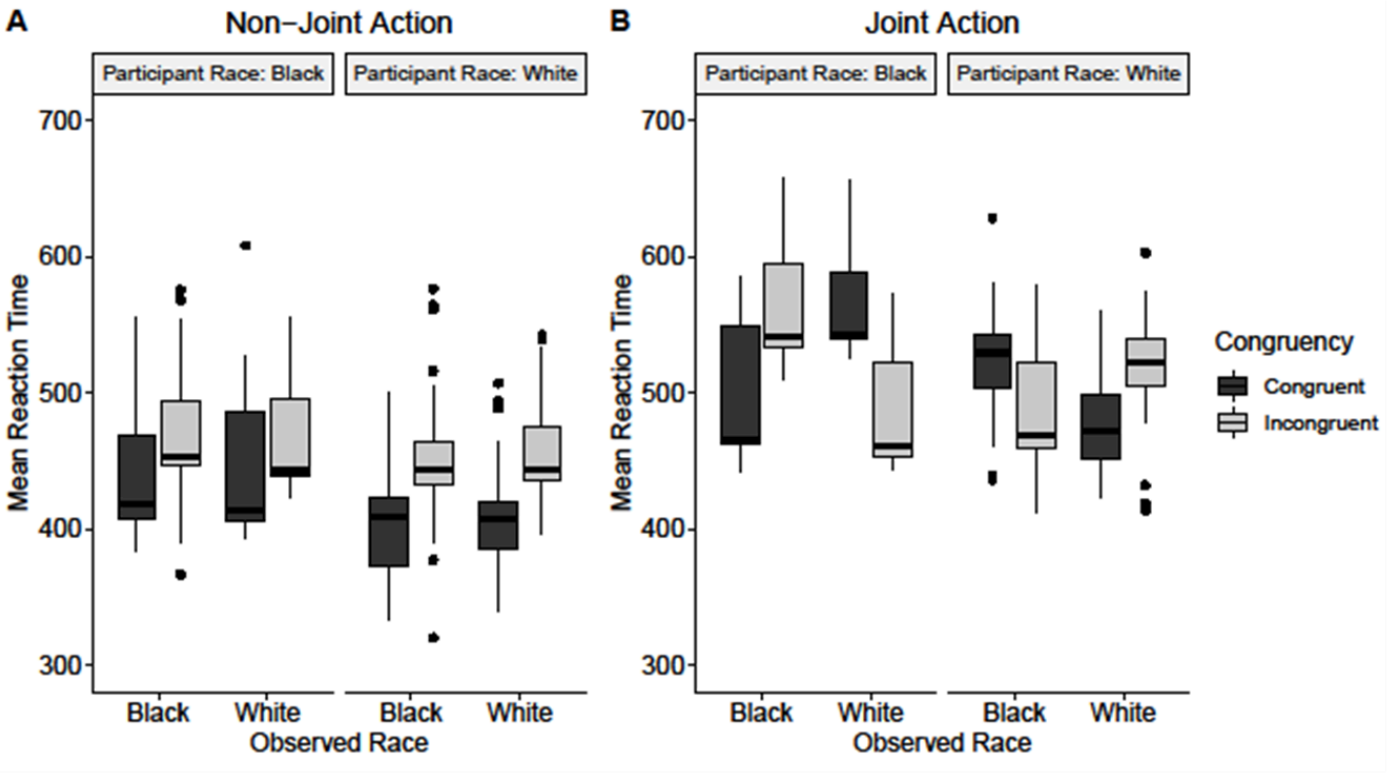


Figure 2

Results Experiment 1. A) For Reaction Times in Non-Joint Action blocks, no interaction was observed between Congruency and Observed Race. B) For Reaction Times in Joint Actions blocks, an interaction was observed between Congruency, Observed Race, and Participant Race. White participants where slower on Incongruent compared to Congruent trials when observing White hands, and were slower on Congruent compared to Incongruent trials when observing Black hands. The reverse pattern was observed for Black participants.

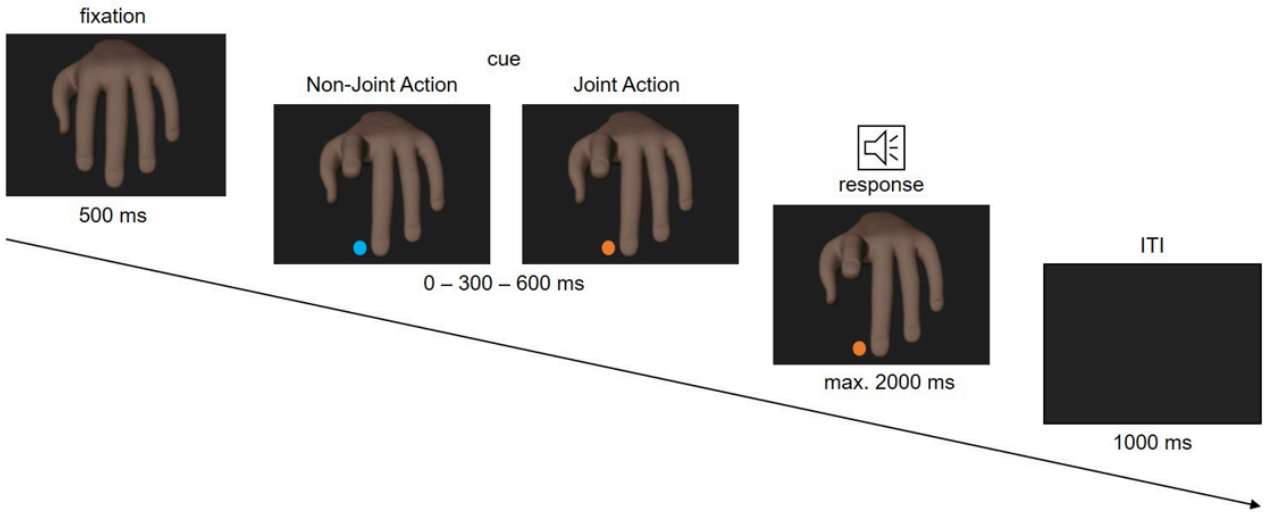


Figure 3

Experimental setup Experiment 2. The task in Experiment 2 was similar to the task in Experiment 1. However, in Experiment 2 the circle cue (purple or blue in Non-Joint Action blocks, yellow or orange in Joint Action blocks) was presented at the same time that the hand on screen made its movement. A sound cue, presented after 0 ms, 300 ms or 600 ms, notified participants about when they had to make the movement.

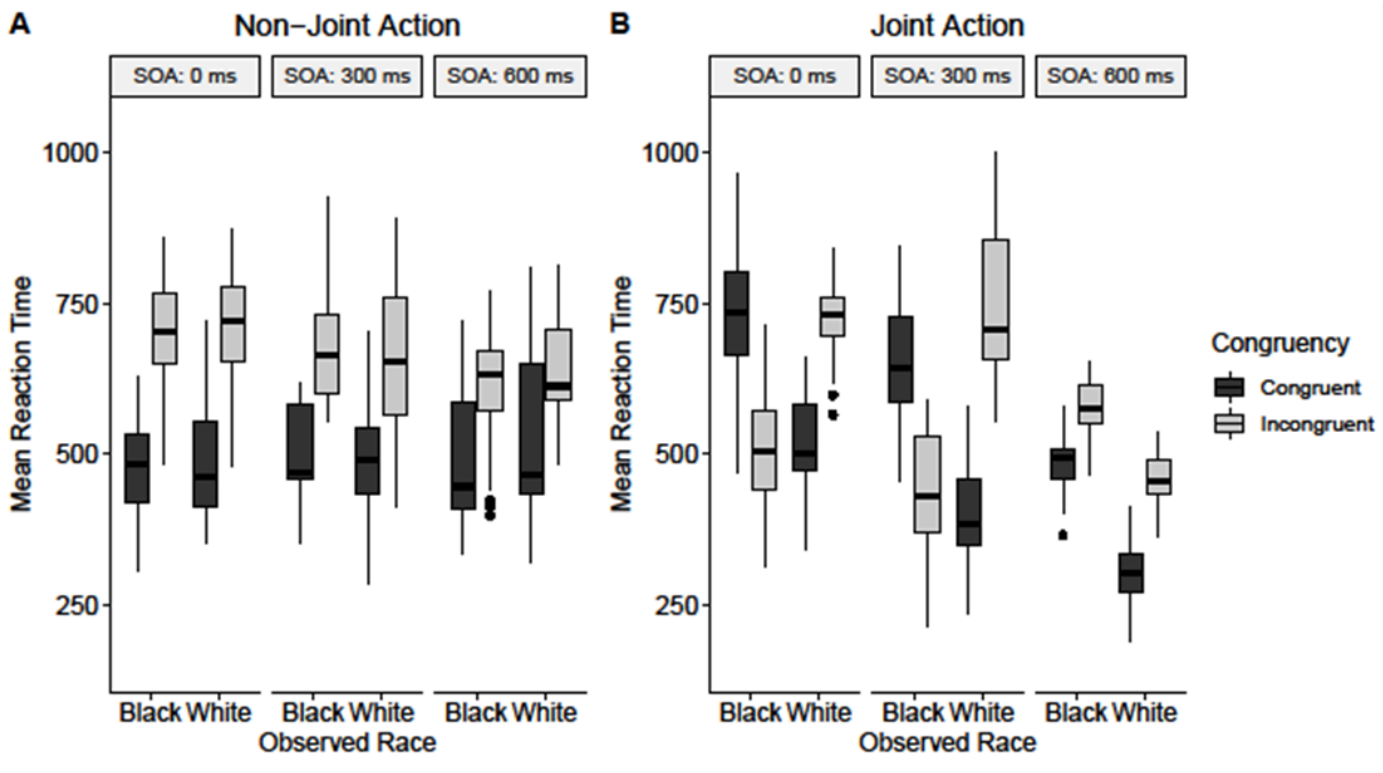


Figure 4

Results Experiment 2. A) For Reaction Times in Non-Joint Action blocks, no interaction was observed between Congruency and Observed Race, or between Congruency, Observed Race, and Stimulus Onset Asynchrony (SOA). B) For Reaction Times in Joint Actions blocks, an interaction was observed between Congruency, Observed Race, and SOA. For 0 ms and 300 ms SOA, participants were slower on Incongruent compared to Congruent trials when observing White hands, and slower on Congruent compared to Incongruent trials when observing Black hands. For 600 ms SOA, participants were slower on Incongruent compared to Congruent trials when observing both White and Black hands.