Observing conflicting actions elicits conflict adaptation

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The stimuli, experimental programs, data, and analyses of all experiments can be found on the Open Science Framework (https://osf.io/ubntz/).

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Abstract

A key prediction of ideomotor theories is that action perception relies on the same mechanisms as action planning. While this prediction has received support from studies investigating action perception in one-on-one interactions, situations with multiple actors pose a challenge because in order to co-represent multiple observed actions, observers have to represent more actions in their motor system than they can physically execute. If representing multiple observed actions, like representing individual observed actions, recycles action planning processes, this should lead to response conflict by observation. In 5 experiments, we tested this hypothesis by investigating whether simply seeing two conflicting actions is sufficient to elicit response conflict and therefore adaptive control in the same way as planning conflicting actions does. Experiments 1-3 provided meta-analytical evidence (N = 262) that seeing two conflicting gestures triggered a reverse congruency sequence effect on a subsequent, unrelated prime-probe task. Experiment 4 (N = 250) replicated this finding in a high-powered study. Finally, Experiment 5 (N = 253) revealed that the same effect was not present when using unfolding abstract shapes instead of moving hands. Together, these experiments show that not just planning but also seeing two conflicting actions elicits adaptive control and they provide initial evidence that this is driven by action conflict. These findings have important implications both for theories of action representation and research on cognitive control.

Keywords: action perception, adaptive control, action conflict, ideomotor theory, multiple agents.

Introduction

A longstanding and important framework to understand intentional behavior is ideomotor theory. Ideomotor theories argue that actions are controlled by imagining their anticipated sensory consequences: we initiate actions by imagining what would happen if we executed them (Greenwald, 1970; Hommel, 2009; Prinz, 1997; Shin et al., 2010). Thus, according to these theories, perception and action share the same mechanisms (Brass & Heyes, 2005; Prinz, 1997). Supporting this view, research has shown that action perception recycles the same brain areas also used for action planning (Caspers et al., 2010; Gazzola & Keysers, 2009). As a result, simply observing an action is enough to trigger an imitative response (Colton et al., 2018; Cracco et al., 2018). However, in social life, we are often surrounded by not just one but multiple people. This poses an important challenge to ideomotor theories because it requires a mechanism geared for representing single actions (i.e., action planning) to be applied to multiple actions at once. Nevertheless, recent evidence suggests that the actions of multiple agents can be represented simultaneously in the motor system (Cracco et al., 2016, 2019), allowing our behavior to be influenced by several people at the same time (Cracco et al., 2015; Cracco & Brass, 2018a, 2018b, 2018c; Cracco & Cooper, 2019).

What remains unclear, however, is exactly how multiple observed actions are represented in the motor system. Here, we test the hypothesis that representing multiple observed actions, like representing single observed actions, recycles action planning processes. If this is the case, then simply seeing incompatible actions should be enough to elicit action conflict, just like planning incompatible actions does (Botvinick et al., 2001, 2004). Initial support for this hypothesis came from a recent fMRI study, where it was found that observing two conflicting actions activates brain areas associated with planning conflicting actions (Cracco et al., 2019), such as the anterior cingulate cortex (ACC;

Botvinick et al., 2001, 2004; Braver et al., 2001; Ridderinkhof et al., 2004). However, while suggestive, it is notoriously difficult to link brain activity to specific cognitive functions (Poldrack, 2006), especially if involved in many processes like the ACC (Shackman et al., 2011; Vassena et al., 2017; Vermeylen et al., 2020).

One way to get around this problem is to look not at the conflict itself but at its behavioral consequences. During action planning, conflict is known to trigger adaptive adjustments in cognitive control (Braem et al., 2019; Bugg & Crump, 2012; Duthoo et al., 2014; Egner, 2007) aimed at improving task performance (Botvinick et al., 2001). One of the most commonly studied examples of adaptive control is the congruency sequence effect — the finding that congruency effects in conflict tasks like the Stroop task (Stroop, 1935) are smaller after incongruent trials, where two conflicting responses are activated, than after congruent trials, where only one response is triggered (Duthoo et al., 2014; Egner, 2007; Gratton et al., 1992). While several explanations for this effect exist (e.g., Botvinick et al., 2001; Egner, 2014; Schmidt, 2013; Verguts & Notebaert, 2008), it is now widely accepted that it can be used as a measure of adaptive control (Braem et al., 2019), because it leads to reduced interference from distracting task-irrelevant features.

Here, we investigate whether adaptive control can be triggered not just by planning but also by observing conflicting actions. Specifically, following ideomotor theory (Brass & Heyes, 2005; Greenwald, 1970; Hommel, 2009; Prinz, 1997; Shin et al., 2010), we predict that seeing two conflicting actions activates two mutually incompatible motor plans (Cracco et al., 2019; Cracco & Brass, 2018b), which in turn generates action conflict (Cracco et al., 2019), and therefore triggers adaptive control. To test this hypothesis, we developed a sequential paradigm in which each trial consisted of two phases (Figure 1): first participants saw two hands performing either identical or conflicting actions and then they did a prime-probe task (Weissman et al., 2014, 2015). If merely seeing two conflicting actions is sufficient to trigger adaptive control, we should see a modulation of the prime-probe congruency effect depending on whether two identical or two conflicting actions were observed. Importantly, the direction of this modulation is known to depend on how the two contexts (i.e., the observation and prime-probe phases) are represented in working memory (Verguts & Notebaert, 2008). Specifically, research suggests that conflict adaptation across contexts is manifested differently when both contexts are maintained together than when they are coded separately (for a review, see Braem et al., 2014). If they are maintained together, we can expect a regular congruency sequence effect, with reduced interference on the prime-probe task (e.g., Kan et al., 2013; Kleiman et al., 2014). In contrast, if they are coded separately, we can expect this effect to be reversed, with increased rather than reduced interference on the prime-probe task (e.g., Notebaert & Verguts, 2008; Scherbaum et al., 2011).

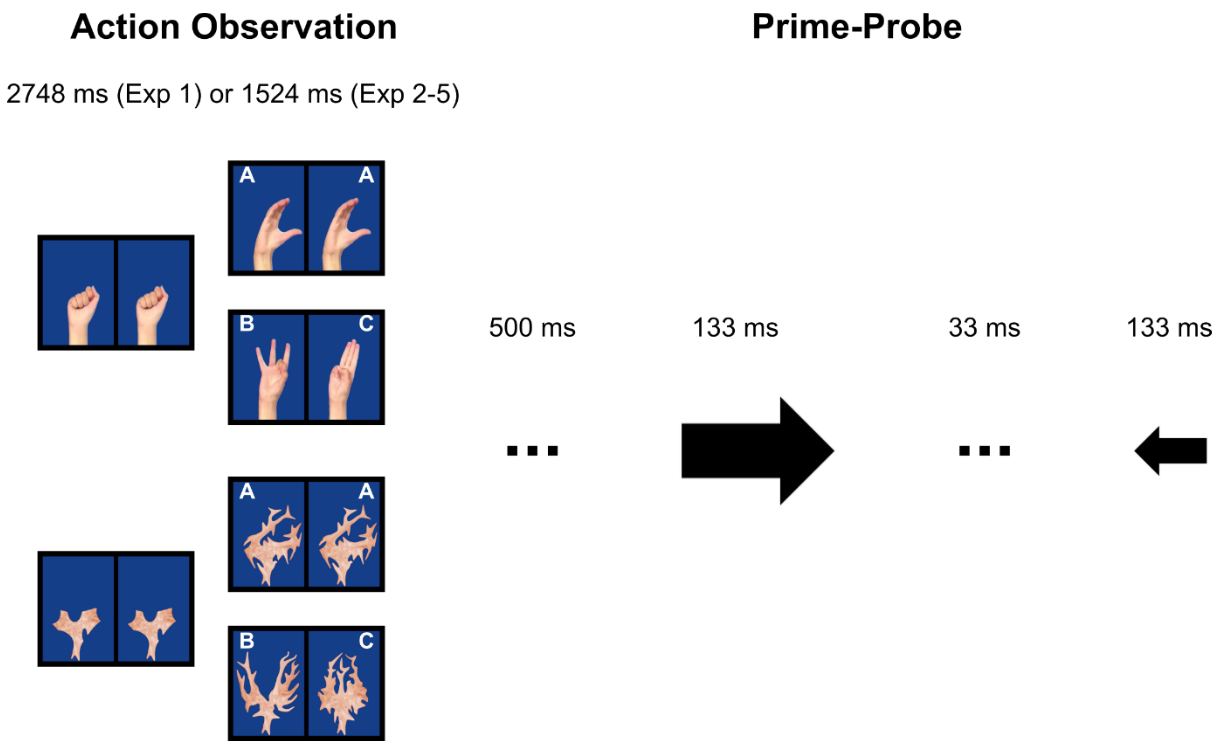

Fig 1. Trial structure. On each trial, participants first saw videos of two identical or two conflicting moving hands (Experiments 1-4) or unfolding abstract shapes (Experiment 5).

Next, they did a prime-probe task. Examples of the action observation stimuli show the start and end positions for the two conditions. The shapes were created to roughly model the hand gestures.

Open Science Statement

The stimuli, experimental programs, data, and analyses of all experiments can be found on the Open Science Framework (https://osf.io/ubntz/). All exploratory analyses are labeled as such.

Experiments 1-3

Methods

Participants. Experiment 1 consisted of 47 participants, Experiment 2 of 88 participants, and Experiment 3 of 140 participants. Experiment 2 (https://aspredicted.org/blind.php?x=pd6ze4) and Experiment 3 (https://aspredicted.org/blind.php?x=e3nz6x) were preregistered. Experiment 2 was powered to have at least 80% power to detect the effects in Experiment 1 after exclusions and Experiment 3 to have at least 90% power to detect the effects in Experiment 2 after exclusions. Following the exclusions mentioned below, 44 participants were retained in Experiment 1 (33 female, M_{age} = 18.77, SD_{age} = 2.10, $range_{age}$ = 18-29), 83 in Experiment 2 (74 female, M_{age} = 18.84, SD_{age} = 1.98, $range_{age}$ = 18-34), and 135 in Experiment 3 (114 female, M_{age} = 18.56, SD_{age} = 1.32, $range_{age}$ = 18-29). Participants were right-handed Ghent University students with normal or corrected-to-normal vision who took part in the experiment in exchange for course credit. All participants signed an informed consent before the start of the study. The study was approved by the Institutional Ethics Committee of the Faculty of Psychology and Educational Sciences at Ghent University.

Task and Procedure. The experiment was programmed in PsychoPy 3 (Peirce et al., 2019) and started with a 10-trial practice phase with accuracy feedback, followed by 4 blocks of 96 trials without feedback. Trials were presented at random and consisted of two phases. In the first phase of the trial, participants saw short videos of two right hands performing one of three sign language gestures (Cracco et al., 2019). The hands performed either two identical or two different, conflicting gestures. There were six possible gesture combinations: G1/G1, G2/G2, G3/G3, G1/G2, G3/G1, and G2/G3. This ensured that each of the three gestures occurred equally often in each condition and on each side of the screen. Videos were presented as a sequence of 28 frames. Before the start of the video, the first frame, showing both hands in their start position, was presented for 300 ms. Next, all 28 frames were presented for 33 ms each, with the last frame remaining on the screen for another 300 ms. Videos were shown twice in Experiment 1 but were presented only once in Experiments 2 and 3. Following the video(s), a blank screen was shown for 500 ms, followed by the second phase of the trial. In the second phase, participants did a prime-probe task. More specifically, a big arrow pointing left or right was shown for 133 ms, followed by a blank screen for 33 ms, and a small arrow pointing in either the same (congruent) or opposite (incongruent) direction for another 133 ms. Participants were required to respond to the small arrow by pressing V with their right index finger if the arrow pointed left and B with their right middle finger if the arrow pointed right. The response deadline was 2000 ms. Following the response, or the response deadline, a blank screen was presented for 1000 ms, after which the next trial started.

To ensure that participants attended to the videos, they were asked to detect glitches occurring randomly on the left hand, right hand, or both hands. Glitches were presented in a randomly selected 12.5% of the trials by replacing one of the 28 frames with a blue frame. In Experiment 1, each glitch was followed by a question asking participants on which hand the glitch had occurred. To respond, participants had to press the V key if the glitch had occurred left, the B key if it had occurred right, and both V and B at the same time if it had occurred on both hands. In Experiment 2, participants were asked to withhold their response on the prime-probe task if they had detected a glitch in the videos. Finally, in Experiment 3, participants had to respond by simultaneously pressing the V and B keys as fast as possible when they detected a glitch.

Data-Analysis. In all three experiments, we excluded participants if their error rate (ER) on either the glitch detection or prime-probe task was below chance or ≥ 3 SD above the sample mean, or if their average reaction time (RT) on the prime-probe task was ≥ 3 SD above the sample mean. This led to the exclusion of 2 participants in Experiment 1, 5 participants in Experiment 2, and 5 participants in Experiment 3. In addition, one further participant was excluded from Experiment 1 because they used both hands to respond instead of just their right hand as instructed.

Trials were excluded from the RT analysis if a glitch had occurred in the video, if participants detected a glitch when there was none (as indicated by their responses), if no response (i.e., RT ≥ 2000 ms) or an incorrect response was provided on the prime-probe task, and if the RT on the prime-probe task was ≤ 100 ms or ≥ 3 SD above the participant's mean RT. Trials were excluded from the ER analysis if a glitch had occurred in the video, if participants detected a glitch when there was none (as indicated by their responses), if no response was provided on the prime-probe task, and if the RT on the prime-probe task was ≤ 100 ms.

The resulting RT and ER data were analyzed using a gesture type (same vs. conflicting) x congruency (congruent vs. incongruent) repeated measures ANOVA. In addition, we also analyzed the combined RT and ER data using inverse efficiency scores (IES), calculated as $\frac{RT}{(1-ER)}$ (Bruyer & Brysbaert, 2011). The IES was included as an exploratory post-hoc measure in Experiment 1 and as a pre-registered secondary measure in Experiments 2 and 3.

Table 1.

Methodological details of each experiment.

	N	Test Environment	Preregistered	Stimuli	Video Cycles	Attention Check
Exp 1	44	Lab	No	Hands	2	Indicate location of glitch
Exp 2	83	Lab	Yes	Hands	1	Withhold prime-probe response if glitch
Exp 3	135	Lab	Yes	Hands	1	Press both keys if glitch
Exp 4	250	Online	Yes	Hands	1	None
Exp 5	253	Online	Yes	Shapes	1	None

Results

RT. The RT analysis (Table 2) revealed a main effect of congruency with faster responses on congruent trials than on incongruent trials in all three experiments: Experiment 1, $F(1, 43) = 65.57$, $p < .001$, $d_z = 1.22$, Experiment 2, $F(1, 82) = 126.31$, $p < .001$, $d_z = 1.23$, Experiment 3, $F(1, 134) = 330.75$, $p < .001$, $d_z = 1.57$. The main effect of gesture type was significant in Experiment 2, $F(1, 82) = 4.34$, $p = .040$, $d_z = 0.23$, but not in Experiment 1, $F(1, 43) = 2.91$, $p = .095$, $d_z = 0.26$, or Experiment 3, $F(1, 134) = 0.95$, $p = .333$, $d_z = 0.08$. In Experiment 2, responses were faster after seeing two conflicting actions than after seeing two identical actions. Finally, the predicted gesture type x congruency interaction was significant in Experiment 2, $F(1, 82) = 6.51$, $p = .013$, $d_z = 0.28$, but not in Experiment 1, $F(1, 43) = 1.21$, $p = .277$, $d_z = 0.17$, or Experiment 3, $F(1, 134) = 0.47$, $p = .496$, $d_z = 0.06$. In

Experiment 2, the congruency effect was stronger after seeing two conflicting actions than after seeing two identical actions.

ER. The ER analysis (Table 2) revealed a main effect of congruency with fewer errors on congruent than on incongruent trials in all three experiments: Experiment 1, $F(1, 43) = 24.25$, $p < .001$, $d_z = 0.74$, Experiment 2, $F(1, 82) = 66.88$, $p < .001$, $d_z = 0.90$, Experiment 3, $F(1, 134) = 142.11$, $p < .001$, $d_z = 1.03$. The main effect of gesture type was significant in Experiment 1, $F(1, 43) = 4.91$, $p = .032$, $d_z = 0.33$, but not in Experiment 2, $F(1, 82) = 0.00$, $p = .954$, $d_z = 0.01$, or in Experiment 3, $F(1, 134) = 0.01$, $p = .925$, $d_z = 0.01$. In Experiment 1, participants made more errors after seeing two conflicting actions than after seeing two identical actions. The congruency x gesture type interaction did not reach statistical significance in any of the three experiments: Experiment 1, $F(1, 43) = 3.21$, $p = .080$, $d_z = 0.27$, Experiment 2, $F(1, 82) = 0.08$, $p = .782$, $d_z = 0.03$, Experiment 3, $F(1, 134) = 2.16$, $p = .144$, $d_z = 0.13$.

IES. The IES analysis (Table 2) indicated a main effect of congruency with smaller IES scores on congruent than incongruent trials in all three experiments: Experiment 1, $F(1, 43) = 51.86$, $p < .001$, $d_z = 1.09$, Experiment 2, $F(1, 82) = 111.63$, $p < .001$, $d_z = 1.16$, Experiment 3, $F(1, 134) = 218.12$, $p < .001$, $d_z = 1.27$. In contrast, the main effect of gesture type was not significant in any of the three experiments: Experiment 1, $F(1, 43) = 0.43$, $p = .513$, $d_z = 0.10$, Experiment 2, $F(1, 82) = 2.04$, $p = .157$, $d_z = 0.16$, Experiment 3, $F(1, 134) = 0.15$, $p = .703$, $d_z = 0.03$. Finally, the interaction between congruency and gesture type was significant in Experiment 1, $F(1, 43) = 4.53$, $p = .039$, $d_z = 0.32$, but not in Experiment 2, $F(1, 82) = 3.50$, $p = .065$, $d_z = 0.21$, or Experiment 3, $F(1, 134) = 1.40$, $p = .239$, $d_z = 0.10$. In Experiment 1, the IES congruency effect was larger after seeing two conflicting actions than after seeing two identical actions.

Table 2.

Prime-probe congruency effects and their standard deviations in Experiments 1-3.

	Exp 1			**Exp 2**			**Exp 3**		
RT	**C**	**IC**	**CE**	**C**	**IC**	**CE**	**C**	**IC**	**CE**
Same	410 ± 58	452 ± 65	42 ± 39	423 ± 58	465 ± 59	43 ± 36	411 ± 48	474 ± 60	63 ± 41
Conflicting	406 ± 57	452 ± 67	46 ± 35	418 ± 54	466 ± 60	48 ± 41	409 ± 47	474 ± 61	64 ± 41
ER	**C**	**IC**	**CE**	**C**	**IC**	**CE**	**C**	**IC**	**CE**
Same	0.6 ± 1.4	5.6 ± 7.3	5.0 ± 6.8	0.7 ± 1.4	5.4 ± 5.8	4.6 ± 5.7	0.9 ± 1.4	8.8 ± 8.5	7.9 ± 8.4
Conflicting	0.7 ± 1.5	6.6 ± 8.4	5.9 ± 8.2	0.7 ± 1.2	5.4 ± 5.7	4.7 ± 5.4	0.6 ± 1.1	9.2 ± 8.6	8.5 ± 8.3
IES	**C**	**IC**	**CE**	**C**	**IC**	**CE**	**C**	**IC**	**CE**
Same	412 ± 57	480 ± 66	68 ± 65	426 ± 58	494 ± 71	68 ± 61	414 ± 47	525 ± 88	111 ± 91
Conflicting	409 ± 55	486 ± 68	77 ± 71	421 ± 54	495 ± 68	74 ± 65	412 ± 46	526 ± 87	114 ± 89

Note. C = congruent, IC = incongruent, CE = congruency effect. Distributions of RT and IES congruency effects can be found in Supplementary material (Supplementary Figures S1 and S2).

Meta-Analysis

The results of the first three experiments provided mixed results in term of statistical significance. However, as can be seen in Table 2, the descriptive results were remarkably consistent across experiments and dependent measures, with numerically larger prime-probe congruency effects after seeing two conflicting compared with two identical actions in all three measures and for all three experiments. Therefore, as an unregistered exploratory analysis, we also ran a fixed effects meta-analysis on the gesture type x congruency interaction observed across our three experiments (Hedges & Vevea, 1998). This revealed a small but significant effect for all three dependent measures, indicating that the congruency effect was stronger after seeing two conflicting actions than after seeing two identical actions: RTs, $d_z = 0.15$, $z = 2.36$, $p = .018$, ERs, $d_z = 0.12$, $z = 1.96$, $p = .050$, IES, $d_z = 0.17$, $z = 2.75$, $p = .006$.

Interim Discussion

The aim of the first three experiments was to test if seeing two conflicting actions suffices to trigger adaptive control (Braem et al., 2019) on a subsequent prime-probe task (Weissman et al., 2014, 2015). The three experiments on their own provided mixed results, with Experiment 1 showing a congruency sequence effect only on IES but not on RTs or ERs, Experiment 2 only on RTs but not on ERs or IES, and Experiment 3 on none of the three dependent measures. Interestingly, however, taking the three experiments together in a mini meta-analysis revealed a small but significant congruency sequence effect on all three measures (RTs, ERs, and IES). Specifically, we found that the prime-probe congruency effect was larger after seeing two conflicting relative to two identical actions.

An increase of the congruency effect following conflict is the opposite of what is typically reported for conflict adaptation within the same context (Duthoo et al., 2014; Egner, 2007; Gratton et al., 1992). However, studies looking at conflict adaptation across contexts often report such reversed congruency sequence effects (e.g., Braem et al., 2011; Brown et al., 2007; Freund & Nozari, 2018; Notebaert & Verguts, 2008; Scherbaum et al., 2011, 2016). A theory that can explain these seemingly contrasting results is the adaptation by binding model (Verguts & Notebaert, 2008, 2009). This model argues that conflict strengthens context-relevant representations at the cost of weakening context-irrelevant representations. On context repetitions, this leads to an increase in cognitive control and therefore a reduction of the congruency effect. In contrast, on context switches, two things can happen. When the two contexts are similar, they are maintained together in working memory. As a result, switching between them leads to a reduction of the congruency effect. In contrast, dissimilar contexts are maintained separately and conflict in one context therefore leads to reduced control in the other context. This is visible as stronger rather than weaker congruency effects on context switches.

Crucially, context in these types of models should be understood in the broadest sense. It entails task-relevant as well as task-irrelevant features (Abrahamse et al., 2016; Braem et al., 2014), perceptual as well as motor representations (Abrahamse et al., 2016), and even entails temporal aspects of the task (Egner, 2014). In the current study, the action observation and prime-probe phases differed on all these aspects: they used different stimuli, had different tasks, and occurred at different times in the trial sequence. As a result, the reversed congruency sequence effect can be explained by conflict in the action observation phase triggering a decrease in attention towards the prime-probe task. Nevertheless, because we were a-priori agnostic about the sign of the congruency sequence effect, and because none of the three experiments provided strong evidence for this effect on their own, it is important to replicate our results in an independent preregistered study. In addition, it is possible that not conflict but rather the attentional task requiring participants to detect glitches in the videos caused the congruency sequence effects observed here. For example, it is conceivable that it was more difficult to detect glitches when the hands performed two conflicting actions because this made for a more complex visual scene. This, in turn, may have hampered switching to the prime-probe task, leading to increased interference from the task-irrelevant information.

As an initial test of this hypothesis, we compared performance on the attentional task when seeing two identical versus two conflicting gestures. This indicated that performance was matched between both conditions in all three experiments: Experiment 1, $t(43) = 0.91$, $p = .368$, Experiment 2, $t(82) = 0.41$, $p = .686$, and Experiment 3, $t(134) = 0.29$, $p = .772$. Nevertheless, it remains a theoretical possibility that these measures were not sensitive enough to detect differences in task difficulty between both conditions. Therefore, the aim of Experiment 4 was to replicate the meta-analytical result observed in Experiments 1-3 without an attentional task.

Experiment 4

Methods

Participants. Experiment 4 was preregistered (http://aspredicted.org/blind.php?x=76rc3u) and powered to detect the meta-analytical IES effect size with at least 80% power[1] after exclusions. In total, 365 participants were tested. Participants were recruited on Prolific and performed the experiment online. After exclusions, 250 participants were retained (107 female, 128 male, 15 unknown gender, $M_{age} = 25.69$, $SD_{age} = 4.48$, $\text{range}_{age} = 18\text{-}35$). Participants were right-handed with normal or corrected-to-normal vision and received £1.70 for participating. All participants explicitly agreed to an informed consent before the start of the study.

Task and Procedure. The experiment was identical to Experiments 2 and 3, with the following exceptions: first, the experiment was programmed not in PsychoPy but in JsPsych (de Leeuw & Motz, 2016). Second, the experiment was completed online instead of in the lab. Third, there was no attentional check during the action observation phase of the trial. This means that none of the videos in Experiment 4 contained a glitch and that participants were not asked to attend to anything in particular. Fourth, the number of trials was halved, so

[1] The meta-analytical IES effect size was originally estimated to be $d_z = 0.18$ due to a coding error in the analysis script of Experiment 1. Fixing this error reduced the effect size to $d_z = 0.17$. The preregistered sample size ensures that Experiment 4 has at least 76% power to detect the corrected effect size.

that now each block comprised not 96 but 48 trials. Fifth, the practice phase was repeated until accuracy on the practice trials was at least 80%. Finally, after the experiment, participants were asked which hand they had used to respond to the stimuli, whether the action videos had played smoothly, and whether they had noticed anything else that they wanted to share.

Data Analysis. Participants were excluded if they reported that they had used their left hand or both hands to respond to the stimuli (N = 107[2]), if they reported that the videos did not play smoothly (N = 0), if their ER on the prime-probe task was below chance or ≥ 3 SD above the sample mean (N = 6), or if their average RT on the prime-probe task was ≥ 3 SD above the sample mean (N = 2). Trials were excluded from the RT analysis if no response (i.e., RT ≥ 2000 ms) or an incorrect response was provided on the prime-probe task or if the RT on the prime-probe task was ≤ 100 ms or ≥ 3 SD above the participant's mean RT. Trials were excluded from the ER analysis if no response was provided on the prime-probe task or if the RT on the prime-probe task was ≤ 100 ms. The resulting RT, ER, and IES data were analyzed using a gesture type (identical vs. conflicting) x congruency (congruent vs. incongruent) repeated measures ANOVA.

Results

RT. The RT results (Table 3) revealed a main effect of congruency, $F(1, 249) = 489.38$, $p < .001$, $d_z = 1.40$, with faster responses on congruent than on incongruent trials, but no main effect of gesture type, $F(1, 249) = 2.29$, $p = .131$, $d_z = 0.10$. Crucially, the

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[2] The reason why we had to exclude many more participants for not using their right hand in Experiments 4 and 5 than in Experiments 1-3 is likely that these were online experiments and that not all participants (sufficiently) read the instructions, or chose to ignore them. An exploratory analysis on the RT data comparing participants who either did or did not use their right hand revealed a hand x gesture type x congruency interaction in Experiment 4, $F(1, 355) = 10.94$, $p = .001$, but not in Experiment 5, $F(1, 378) = 0.00$, $p = .993$. Further exploring this 3-way interaction in Experiment 4 showed that, in contrast to participants using their right hand, the gesture type x congruency was not significant for participants using their left hand or both hands, $F(1, 106) = 2.65$, $p = .107$.

congruency x gesture type interaction was also significant, $F(1, 249) = 11.18$, $p < .001$, d_z = 0.21. In line with Experiments 1-3, the congruency effect was stronger after seeing two conflicting actions than after seeing two identical actions.

ER. The ER results (Table 3) revealed a main effect of congruency, $F(1, 249)$ = 152.88, $p < .001$, $d_z = 0.78$, with fewer errors on congruent than on incongruent trials, but no main effect of gesture type, $F(1, 249) = 2.19$, $p = .140$, $d_z = 0.09$. The congruency x gesture type interaction was again significant, $F(1, 249) = 4.83$, $p = .029$, $d_z = 0.14$. In line with RTs, the congruency effect was stronger after seeing two conflicting actions than after seeing two identical actions.

IES. The IES results (Table 3) revealed a main effect of congruency, $F(1, 249)$ = 409.05, $p < .001$, $d_z = 1.28$, with a smaller IES on congruent than on incongruent trials, but no main effect of gesture type, $F(1, 249) = 0.02$, $p = .888$, $d_z = 0.01$. The congruency x gesture type interaction was also significant, $F(1, 249) = 11.87$, p < .001, $d_z = 0.22$, and again indicated that the congruency effect was stronger after seeing two conflicting actions than after seeing two identical actions.

Table 3.

Prime-probe congruency effects and their standard deviation in Experiments 4 and 5.

	Exp 4			Exp 5		
RT	**C**	**IC**	**CE**	**C**	**IC**	**CE**
Same	442 ± 59	486 ± 66	44 ± 33	444 ± 57	487 ± 62	43 ± 31
Conflicting	439 ± 57	487 ± 67	48 ± 36	445 ± 56	489 ± 63	44 ± 31
ER	**C**	**IC**	**CE**	**C**	**IC**	**CE**
Same	0.7 ± 1.8	4.4 ± 5.6	3.7 ± 5.5	0.5 ± 1.3	4.1 ± 5.6	3.6 ± 5.6
Conflicting	0.5 ± 1.5	4.9 ± 5.9	4.4 ± 5.8	0.5 ± 1.1	4.2 ± 5.4	3.8 ± 5.3
IES	**C**	**IC**	**CE**	**C**	**IC**	**CE**
Same	445 ± 60	510 ± 73	65 ± 55	447 ± 57	509 ± 62	62 ± 49
Conflicting	442 ± 58	514 ± 73	72 ± 58	447 ± 56	511 ± 63	64 ± 48

Note. C = congruent, IC = incongruent, CE = congruency effect. Distributions of RT and IES congruency effects can be found in Supplementary material (Supplementary Figures S1 and S2).

Bayesian Analysis. To obtain a more complete picture of the data, we also ran an exploratory Bayesian analysis on the gesture type x congruency interaction effect, using a truncated normal distribution with mean $d_z = 0.30$ and SD = 0.20 as prior (Gronau et al., 2020). We chose $d_z = 0.30$ rather than the meta-analytical effect size across Experiments 1-3 to make the predictions of the null and alternative hypotheses sufficiently distinct. The choice for $d_z = 0.30$ and SD = 0.20 was motivated by the fact that this assigns high probability (84%) to small effect sizes ($0.00 < d_z < 0.50$) under Cohen's rules of thumb (1988) but low probability to medium or large effect sizes. Hence, while our Bayesian analysis says little about the consistency of the data with models assuming even smaller (or larger) effect sizes, it does tell us whether the data is more consistent with a small effect than with no effect. The resulting Bayes Factors (BF) indicated that the RT (BF_{10} = 66.23), ER (BF_{10} = 2.75), and IES (BF_{10} = 113.09) data were all more likely under the alternative model than under the null model (Figure 2). A sensitivity analysis in which we varied the prior SD between 0.1 and 1 in steps of 0.1 further showed that the BF was $22.88 \leq BF_{10} \leq 90.13$ for RTs, $1.14 \leq BF_{10} \leq 2.75$ for ERs, and $38.34 \leq BF_{10} \leq 160.31$ for IES. Together, this indicates strong evidence for a small gesture type x congruency interaction for RTs and IES and anecdotal evidence for ERs (Jeffreys, 1961).

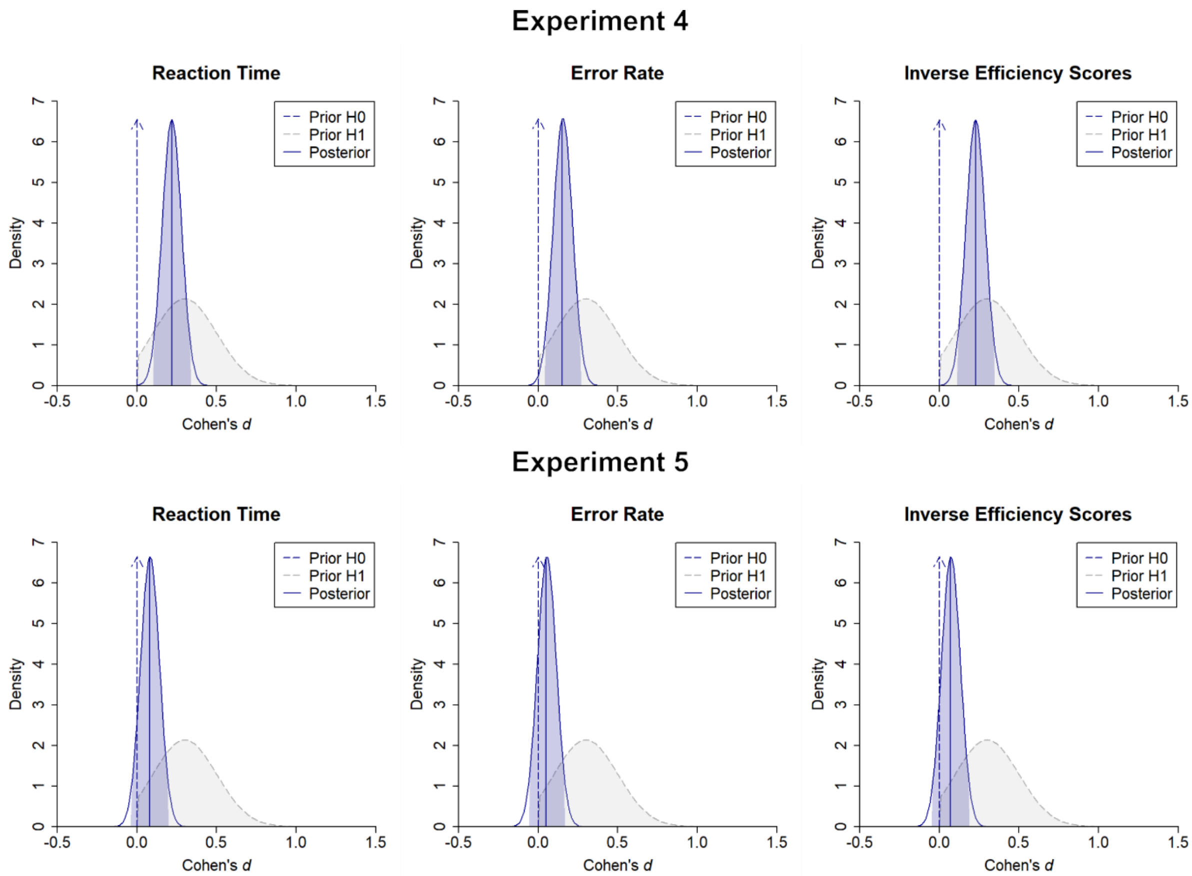

Figure 2. Prior and posterior distributions for the gesture type x congruency effect in reaction times (left), error rates (middle), and inverse efficiency scores (right) of Experiments 4 and 5.

Reaction Time Distribution Analysis. As a second exploratory analysis, we conducted a RT distribution analysis (Ratcliff, 1979). Given the sequential nature of the prime-probe task, congruency effects are likely to be larger on early RTs. Consequently, if seeing two conflicting actions speeds up responses, this could potentially explain the gesture type x congruency interaction. While there was no statistical evidence supporting this hypothesis in Experiment 4, RTs were indeed descriptively smaller after seeing two conflicting actions than after seeing two identical gestures. To test if this could explain the gesture type x congruency interaction, we ranked RTs per participant and per condition from fastest to slowest and ran a linear mixed effects model on the RT data that tested whether the gesture type x congruency interaction was modulated by trial-by-trial variations in the relative response speed (i.e., the rank of the RT in the relevant condition). As expected, this showed a congruency x RT rank interaction, $t(45340) = 12.37$, $p < .001$, indicating that the congruency effect decreased for slower responses (Figure 3). It also revealed a gesture type x congruency x RT rank interaction, $t(45330) = 2.81$, $p = .005$. Importantly, this indicated that the gesture type x congruency became not weaker but stronger for late responses (Figure 3).

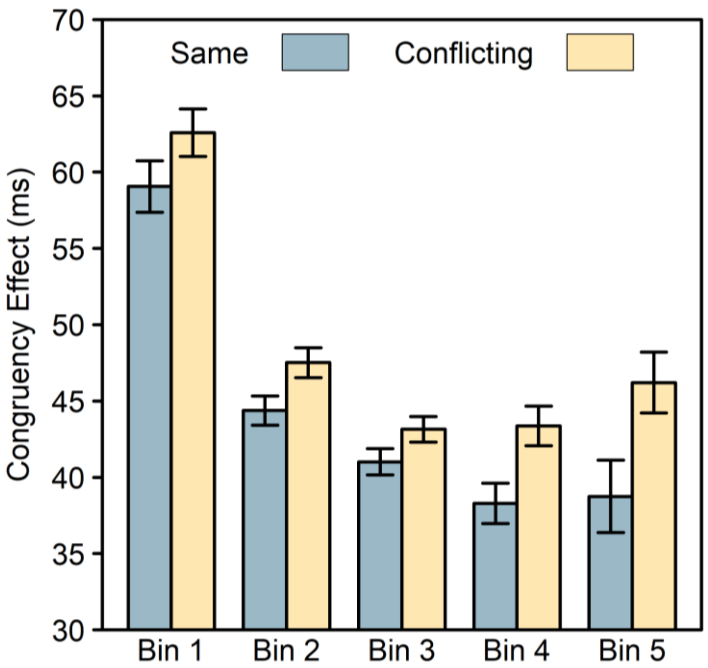

Figure 3. RT distribution results of Experiment 4. RTs were ranked per participant and per condition from fast to slow and these ranks were then included in a linear mixed effects analysis testing whether performance depended on response speed. For illustration purposes,

RTs were divided into 5 bins based on their rank, with bin 1 reflecting the fastest RTs and bin 5 reflecting the slowest RTs. Each bar shows the RT congruency effect in the relevant condition. Error bars are standard errors corrected for within-subject designs according to Morey (2008).

Meta-Analysis

Finally, to obtain further insight into the mechanisms underlying our effects, we conducted two exploratory meta-analyses on the combined RT data of Experiments 1-4. These two analyses tested, respectively, whether different combinations of conflicting gestures produced different effects and whether seeing conflicting gestures on trial N-1 changed the congruency sequence effect on trial N. We conducted these analyses across rather than within experiments because we expected the effects to be considerably smaller than the congruency sequence effect and therefore anticipated each individual experiment to be underpowered. In each of the meta-analyses, standardized difference scores were computed to reflect the effect of interest in terms of Cohen's *d* and these were compared against 0 using a two-tailed test.

Gesture Combinations. In a first analysis, we investigated how the congruency effect was influenced by different combinations of conflicting gestures. If our results were driven by action conflict, the congruency effect should vary as a function of how conflicting the kinematics of the two gestures were. As Figure 1 shows, gestures B and C were clearly more similar to each other than to gesture A. Hence, the prime-probe congruency effect should be smaller after seeing B/C than after seeing A/B or C/A. In line with this hypothesis, the congruency effect was indeed smaller after B/C than after A/B, $d_z = 0.10$, $z = 2.25$, $p = .024$, or C/A, $d_z = 0.10$, $z = 2.24$, $p = .025$, but did not differ between A/B and C/A, $d_z = 0.00$, $z = 0.03$, $p = .976$ (Supplementary Figure S3).

Congruency Sequence Effect Across Trials. In a second analysis, we investigated whether seeing two conflicting gestures on trial N-1 modulated the influence of the gestures on trial N. According to the adaptation by binding account (Verguts & Notebaert, 2008), experiencing conflict increases attention to context-relevant information and decreases attention to context-irrelevant information. While a larger congruency effect after seeing two conflicting gestures provides evidence for reduced control in the prime-probe task, it does not directly show that control was also increased in the action observation context. If it was, then conflicting actions on trial N can be expected to trigger less conflict when preceded by conflicting actions on trial N-1.

To test this hypothesis, we examined whether the gesture type x congruency interaction on trial N was modulated by gesture type on trial N-1. Note that for this analysis, we excluded trials for which the previous trial contained a glitch or was incongruent. The latter was done to remove conflict adaptation effects driven by prime-probe congruency. The results revealed that the reversed congruency sequence effect on trial N was weaker after seeing two conflicting gestures than after seeing two identical gestures on trial N-1, $d_z = 0.11$, $z = 2.47$, $p = .013$. Post-hoc tests further exploring this effect showed that the reversed congruency sequence effect on trial N was significant after seeing two identical gestures on trial N-1, $d_z = 0.14$, $z = 3.03$, $p = .002$, but not after seeing two conflicting gestures on trial N-1, $d_z = 0.03$, $z = 0.76$, $p = .446$.

Interim Discussion

Experiment 4 replicated the meta-analytical results of Experiments 1-3 even when participants did not have an explicit task in the action observation phase. That is, we found a larger congruency effect on the prime-probe task after seeing two conflicting actions than after seeing two identical actions. While this effect was small, a Bayesian analysis revealed that the evidence, at least for RTs, was strong. This indicates that, in line with our hypothesis, observing conflicting actions elicits an action conflict signal that then in turn triggers conflict adaptation effects that are visible as reduced control on unrelated tasks (Verguts & Notebaert, 2009).

This interpretation was further supported by three additional, exploratory analyses. First, a RT distribution analysis indicated that the gesture type x congruency interaction was stronger for slow than for fast responses. Interestingly, this was true even though the congruency effect as such was weaker for slow responses. Consistent with the sequential nature of the prime-probe task, a smaller congruency effect for slow responses suggests that the relative influence of the target over the distractor increased over time. As a result, the finding that the congruency sequence effect increased with response time indicates that it was primarily related to the processing of the target. This is consistent with the adaptation by binding account, which argues that the reversal of the congruency sequence effect on context switches is driven by reduced attention towards task-relevant aspects of the irrelevant context (Verguts & Notebaert, 2008).

Second, we found that the influence of the gestures on the prime-probe task was larger for gestures with low compared to high kinematic overlap. This suggests that our results were not just driven by whether participants saw two identical or two different actions, but rather by whether the two gestures activated similar or conflicting motor programs. Finally, we found that seeing conflicting gestures not only influenced the prime probe task, but also the processing of the observed gestures. That is, we found that the reversed congruency sequence effect on trial N was weaker after seeing two conflicting gestures on trial N-1. This suggests that seeing two conflicting gestures on trial N elicited less conflict and therefore less adaptation when it was preceded by two conflicting gestures on trial N-1.

In other words, it suggests that conflict adaptation took place not only across contexts (from observation to prime-probe) but also within contexts (from observation to observation).

Importantly, however, these three exploratory analyses were unplanned and should therefore be interpreted with care. In addition, a potential alternative explanation could still be that it was not action conflict but rather a more abstract form of stimulus conflict that drove our results (Verbruggen et al., 2006; Wendelken et al., 2009). That is, two conflicting observed actions are conflicting not only at the motor level, but also to some extent at the visual level. Hence, it is possible that any two conflicting stimuli, regardless of whether they elicit action conflict, would trigger conflict adaptation. To rule out this possibility, we conducted a fifth experiment in which we used unfolding abstract shapes instead of actions (Figure 1). Given that both types of stimuli are highly similar but that shapes are unlikely to elicit motor activation, the absence of a congruency modulation in Experiment 5 would support the hypothesis that the effects observed in Experiments 1-4 were caused by action and not perceptual conflict.

Experiment 5

Methods

Participants. Like Experiment 4, Experiment 5 was conducted online via Prolific. Experiment 5 was preregistered (https://aspredicted.org/blind.php?x=2zw8fa) following the same procedure as Experiment 4. In total, 386 participants were tested. After exclusions, 253 participants were retained (116 female, 134 male, 3 non-binary, M_{age} = 26.31, SD_{age} = 4.85, $range_{age}$ = 18-35). Participants were right-handed with normal or corrected-to-normal vision and received £1.70 for participating. All participants explicitly agreed to an informed consent before the start of the study.

Task and Procedure. The task and procedure were identical to Experiment 4, except that instead of moving hands, participants saw unfolding abstract shapes (Figure 1).

Data Analysis. Participants were excluded if they reported that they had used their left hand or both hands to respond to the stimuli (N = 127), if they reported that the videos did not play smoothly (N = 0), if their ER on the prime-probe task was below chance or ≥ 3 SD above the sample mean (N = 4), or if their average RT on the prime-probe task was ≥ 3 SD above the sample mean (N = 2). Trials were excluded from the RT analysis if no response (i.e., RT ≥ 2000 ms) or an incorrect response was provided on the prime-probe task or if the RT on the prime-probe task was ≤ 100 ms or ≥ 3 SD above the participant's mean RT. Trials were excluded from the ER analysis if no response was provided on the prime-probe task or if the RT on the prime-probe task was ≤ 100 ms. The resulting RT, ER, and IES data were analyzed using a gesture type (identical vs. conflicting) x congruency (congruent vs. incongruent) repeated measures ANOVA.

Results

RT. The RT results (Table 3) revealed a main effect of congruency, $F(1, 252) = 543.13$, $p < .001$, $d_z = 1.47$, with faster responses on congruent than on incongruent trials, and a non-significant effect of gesture type, $F(1, 252) = 3.87$, $p = .050$, $d_z = 0.12$, hinting towards slower responses after seeing two conflicting actions than after seeing two identical actions. Importantly, and in contrast to Experiment 4, the gesture type x congruency interaction was not significant, $F(1, 252) = 0.99$, $p = .322$, $d_z = 0.06$. A secondary analysis comparing the results of Experiment 4 to the results of Experiment 5 revealed that the experiment x gesture type x congruency interaction was not significant, $F(1, 501) = 3.44$, $p = .064$, $d_z = 0.17$, although it was close to it, with a numerically larger gesture type x congruency interaction in Experiment 4 than in Experiment 5.

ER. The ER results (Table 3) revealed a main effect of congruency, $F(1, 252) = 141.33$, $p < .001$, $d_z = 0.75$, with fewer errors on congruent than on incongruent trials, but no main effect of gesture type, $F(1, 252) = 0.03$, $p = .875$, $d_z = 0.01$. Similar to RTs, the gesture type x congruency interaction was not significant, $F(1, 252) = 0.29$, $p = .590$, $d_z = 0.03$. A secondary analysis comparing the results of Experiments 4 and 5 showed that the experiment x gesture type x congruency interaction was not significant, $F(1, 501) = 1.34$, $p = .247$, $d_z = 0.10$.

IES. The IES results (Table 3) revealed a main effect of congruency, $F(1, 252) = 481.61$, $p < .001$, $d_z = 1.38$, indicating that the IES was smaller on congruent than on incongruent trials, but no main effect of gesture type, $F(1, 252) = 1.82$, $p = .179$, $d_z = 0.08$. The gesture type x congruency interaction was again not significant, $F(1, 252) = 0.75$, $p = .388$, $d_z = 0.05$. A secondary analysis comparing Experiment 4 and 5 revealed that the experiment x gesture type x congruency interaction was not significant, $F(1, 501) = 3.62$, $p = .058$, $d_z = 0.17$, but was close to it, with a numerically larger gesture type x congruency interaction in Experiment 4 than in Experiment 5.

Bayesian Analysis. Similar to Experiment 4, we followed up on the above results with an exploratory Bayesian analysis on the gesture type x congruency interaction effect, using a truncated normal distribution with mean $d_z = 0.30$ and SD = 0.20 as prior (Gronau et al., 2020). This revealed that the RT ($BF_{01} = 4.16$), ER ($BF_{01} = 7.78$), and IES ($BF_{01} = 5.20$) data were all more likely under the null model than under the alternative model (Figure 2). Sensitivity analyses in which we varied the prior SD between 0.1 and 1 in steps of 0.1 revealed that the BF_{01} was $4.05 \leq BF_{01} \leq 9.42$ for RTs, $7.20 \leq BF_{01} \leq 23.33$ for ERs, and $4.97 \leq BF_{01} \leq 12.96$ for IES. Opposite to Experiment 4, a Bayesian analysis of Experiment 5 thus provided moderate to strong evidence against a small gesture type x congruency interaction (Jeffreys, 1961).

Interim Discussion

In line with our hypothesis, Experiment 5 revealed no congruency modulation, even though the stimuli were perceptually similar to the stimuli used in Experiment 4. This supports the idea that the effects observed in the first four experiments were due to action and not perceptual conflict. That said, it should be noted that a direct comparison of Experiments 4 and 5 did not reach our predefined significance level, although it was close to it. Importantly, however, this comparison was severely underpowered. That is, interaction effects showing that an effect is weaker under one condition than under another are known to be at least twice as small as the original effect (Giner-Sorolla, 2018). A power analysis on $d_z = 0.11$ (i.e., half the size of the RT effect in Experiment 4) revealed that 1300 participants per experiment would have been necessary to obtain 80% power to detect such a difference. Using the current sample sizes, the effect size in Experiment 5 would have had to be almost exactly zero (or in the opposite direction) to be significantly different from Experiment 4. Together with the fact that our Bayesian analysis revealed strong evidence for a small effect in Experiment 4 and moderate to strong evidence against such an effect in Experiment 5, this suggests that our results can be interpreted as cautious support for the hypothesis that conflict adaptation following action observation does not generalize to non-action related stimuli.

General Discussion

A core prediction of ideomotor theory is that action perception relies on the same mechanisms as action planning (Brass & Heyes, 2005; Prinz, 1997). While this prediction has received support from research investigating action perception in one-on-one situations (for reviews, see Caspers et al., 2010; Cracco et al., 2018; Fox et al., 2016; Naish et al., 2014), situations with multiple agents pose an important challenge because such situations require the motor system to represent more actions than the observer can physically execute.

Nevertheless, recent evidence suggests that it is possible to simultaneously co-represent the actions of multiple individuals in the motor system (Cracco et al., 2015, 2016, 2019; Cracco & Brass, 2018a, 2018b, 2018c; Cracco & Cooper, 2019). Here, we directly tested the hypothesis, derived from ideomotor theory, that co-representing multiple observed actions, like co-representing single actions, recycles mechanisms used for action planning. Specifically, we investigated in five experiments (N = 765) whether simply seeing two conflicting actions is sufficient to generate action conflict and therefore to trigger conflict adaptation in the form of congruency sequence effects (Braem et al., 2019), as has often been shown for action planning (Botvinick et al., 2001, 2004). As predicted, Experiments 1-4 revealed that seeing two conflicting relative to two identical actions modulated the congruency effect in a subsequent prime-probe task. In contrast, seeing two conflicting unfolding abstract shapes had no influence on the prime-probe task. These findings suggest that simply observing conflicting actions is sufficient to elicit an action conflict signal and to trigger adaptive control.

Interestingly, the prime-probe congruency effect was not smaller but larger after seeing two conflicting gestures. While this is opposite to what is usually found on context repetitions (Duthoo et al., 2014; Egner, 2007; Gratton et al., 1992), reversed congruency sequence effects are not uncommon on context switches (e.g., Braem et al., 2011; Brown et al., 2007; Freund & Nozari, 2018; Notebaert & Verguts, 2008; Scherbaum et al., 2011, 2016). Such effects are consistent with the adaptation by binding account (Verguts & Notebaert, 2008, 2009), which argues that increased attention to context-relevant information after conflict comes at the cost of reduced attention to context-irrelevant information. In the current study, this means that seeing conflicting gestures led to a reduction of control in the prime-probe task and therefore to a larger congruency effect. Importantly, as any change in the congruency effect, regardless of its sign, suggests a change in cognitive control, this supports the theoretical prediction that perceiving conflicting actions generates action conflict just like planning conflicting actions does.

Action conflict generated by the perception of conflicting actions might have an important social function, as it could help us interpret conflicting social scenes. That is, in line with previous work, we argue that people automatically represent the actions of individuals in their immediate surrounding, both visually and motorically (Cracco et al., 2016, 2019), incorporate these actions in their action plans (Cracco et al., 2015; Cracco & Brass, 2018a, 2018b, 2018c; Cracco & Cooper, 2019), and use them as social cues to guide their own behavior (Gallup et al., 2012; Latane, 1981; Milgram et al., 1969). The current findings suggest that when these cues are conflicting, this generates a conflict signal (Cracco et al., 2019) that probes individuals to more deeply process the visual scene in order to understand and resolve the conflict and potentially adjust their course of action (Shamay-Tsoory et al., 2019).

Importantly, such a mechanism might be relevant for social cognition even though we found only small effect sizes. The reason why we found small effects is likely that even though the motor system is reliably activated by observed actions (Caspers et al., 2010), motor activity is considerably weaker during action observation than during action planning. Given that both conflict and conflict adaptation are proportional to the strength with which conflicting actions are activated (e.g., Botvinick et al., 2001; Verguts & Notebaert, 2008), conflict adaptation induced through action observation is necessarily smaller than that induced through action planning. This is especially true considering that we did not study the influence of seeing conflicting actions on the processing of those actions themselves but rather on an unrelated task. Since conflict adaptation is typically smaller across contexts than within (Braem et al., 2014; Verguts & Notebaert, 2009), decreased attention to the prime-probe task tells us little about how much attention was increased towards the observed gestures.

An exploratory analysis did, however, suggest that seeing conflicting gestures influenced not only the prime-probe task but also the processing of the gestures themselves. Similarly, in a previous fMRI study with the same stimuli, seeing conflicting actions strongly activated the ACC and this activation was reliably correlated with activation in the visuomotor areas involved in processing those actions (Cracco et al., 2019). As the ACC is known to respond to action conflict (Botvinick et al., 2001, 2004; Braver et al., 2001; Ridderinkhof et al., 2004), these findings support the hypothesis that seeing two conflicting actions generates a conflict signal that triggers increased processing of those actions to reduce future conflict. However, direct evidence for this hypothesis is still lacking, and future research will be needed to investigate the hypothesis, as well as its potential social function, more closely.

The current research also has important implications for research on cognitive control. First, our findings provide evidence for the hypothesis that not just planning but also observing conflicting actions can elicit a conflict signal and trigger adjustments in control. Second, we show that conflict adaptation on context switches is manifested as reduced, not increased, cognitive control (e.g., Braem et al., 2011; Brown et al., 2007; Freund & Nozari, 2018; Notebaert & Verguts, 2008; Scherbaum et al., 2011, 2016), thereby supporting previous evidence that conflict-induced increases in control are limited to the context in which the conflict was experienced (e.g., Dignath et al., 2019; Grant et al., 2020; for a review, see Braem et al., 2014).

Interestingly, this conclusion stands in direct contrast with the results obtained by Kan et al. (2013), who like us also investigated conflict adaptation across both conflict type and task structure. In particular, these authors investigated, in their second experiment, whether perceptual conflict can influence a verbal task by first showing participants a series of ambiguous (i.e., incongruent) or unambiguous (i.e., congruent) Necker cubes before they did a Stroop task. The results revealed that the congruency effect on the Stroop task was smaller after seeing incongruent than after seeing congruent Necker cubes. However, a recent registered replication study failed to replicate these findings (Aczel et al., 2019). Hence, there is currently very little evidence that conflict in one context can increase control in another context. Here, we show that conflict in a perceptual task can affect performance in a cognitive task, but that it does so by decreasing rather than increasing control, consistent with what the adaptation by binding account predicts for tasks sharing no features (Verguts & Notebaert, 2008, 2009).

Finally, our findings tentatively suggest that adjustments in the prime-probe congruency effect were driven by action conflict, which resulted from representing both observed actions motorically (Caspers et al., 2010; Cracco et al., 2018; Naish et al., 2014), and not by a more abstract type of perceptual conflict. More specifically, Experiment 5 showed that no congruency sequence effect was present when using unfolding action-unrelated shapes instead of gestures. This was confirmed by a Bayesian analysis showing that the effect in Experiment 5 was more consistent with the null model than with a model assuming a small effect size. Yet, an interpretation in terms of action conflict may seem at odds with research on limb apraxia, showing that apraxia patients have difficulties pantomiming tool-related actions for which there is high conflict between using and grasping the tool, but are nevertheless able to recognize those actions (e.g., Garcea et al., 2019; Lee et al., 2014; Myung et al., 2010; Watson & Buxbaum, 2015). That is, these studies could be taken as evidence that conflict during action execution and during action observation operate at a different level. However, in these studies, what differed between both tasks was not the type of conflict, as conflict between using and grasping a tool only exists at the motor level, but whether and how the conflict has to be resolved. More specifically, while resolving such conflict is necessary to perform the appropriate action, it is not necessary to recognize the action. In other words, while these studies tell us about the level at which conflict is resolved, they tell us little about the level at which conflict was experienced in the first place.

Nevertheless, it remains important to note that the congruency sequence effect in Experiment 5, although not detectable, did not differ significantly from the congruency sequence effect in Experiment 4. As pointed out in the discussion of Experiment 5, this is not surprising, considering that this comparison was severely underpowered. However, it does indicate that at present the evidence for action versus perceptual conflict is only tentative and that further research using more sensitive measures will be needed to further resolve this issue. Regardless, whatever the type of conflict, the point stands that observing conflicting gestures elicits a conflict signal that leads to adaptive control effects visible on a second, unrelated task.

To conclude, the current study shows that not only planning but also simply seeing two conflicting actions can trigger adaptive control mechanisms, visible in the form of a reversed congruency sequence effect on a subsequent yet unrelated prime-probe task. Our results also suggest that these control mechanisms are driven mainly by action rather than perceptual conflict, although this will have to be confirmed in future work. These findings have important implications for theories of action representation, for understanding how humans deal with conflicting social triggers, and for the literature on (adaptive) control processes.

References

Abrahamse, E. L., Braem, S., Notebaert, W., & Verguts, T. (2016). Grounding cognitive control in associative learning. *Psychological Bulletin*, *142*(7), 693–728. https://doi.org/10.1037/bul0000047

Aczel, B., Kovacs, M., Bognar, M., Palfi, B., Hartanto, A., Onie, S., & Evans, T. R. (2019). *Is there evidence for cross-domain congruency sequence effect? A replication of Kan et al. (2013)*. PsyArXiv. https://doi.org/10.31234/osf.io/5k8rq

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict Monitoring and Cognitive Control. *Psychological Review*, *108*(3), 624–652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*(12), 539–546. https://doi.org/10.1016/j.tics.2004.10.003

Braem, S., Abrahamse, E. L., Duthoo, W., & Notebaert, W. (2014). What determines the specificity of conflict adaptation? A review, critical analysis, and proposed synthesis. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01134

Braem, S., Bugg, J. M., Schmidt, J. R., Crump, M. J. C., Weissman, D. H., Notebaert, W., & Egner, T. (2019). Measuring Adaptive Control in Conflict Tasks. *Trends in Cognitive Sciences*, *23*(9), 769–783. https://doi.org/10.1016/j.tics.2019.07.002

Braem, S., Verguts, T., & Notebaert, W. (2011). Conflict adaptation by means of associative learning. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(5), 1662–1666. https://doi.org/10.1037/a0024385

Brass, M., & Heyes, C. (2005). Imitation: Is cognitive neuroscience solving the correspondence problem? *Trends In Cognitive Sciences*, *9*(10), 489–495. https://doi.org/10.1016/j.tics.2005.08.007

Braver, T. S., Barch, D. M., Gray, J. R., Molfese, D. L., & Snyder, A. (2001). Anterior cingulate cortex and response conflict: Effects of frequency, inhibition and errors. *Cerebral Cortex*, *11*(9), 825–836. https://doi.org/10.1093/cercor/11.9.825

Brown, J. W., Reynolds, J. R., & Braver, T. S. (2007). A computational model of fractionated conflict-control mechanisms in task-switching. *Cognitive Psychology*, *55*(1), 37–85. https://doi.org/10.1016/j.cogpsych.2006.09.005

Bruyer, R., & Brysbaert, M. (2011). Combining speed and accuracy in cognitive psychology: Is the inverse efficiency score (IES) a better dependent variable than the mean reaction time (RT) and the percentage of errors (PE)? *Psychologica Belgica*, *51*(1), 5–13. https://doi.org/10.5334/pb-51-1-5

Bugg, J. M., & Crump, M. J. C. (2012). In support of a distinction between voluntary and stimulus-driven control: A review of the literature on proportion congruent effects. *Frontiers in Psychology*, *3*, 1–16. https://doi.org/10.3389/fpsyg.2012.00367

Caspers, S., Zilles, K., Laird, A. R., & Eickhoff, S. B. (2010). ALE meta-analysis of action observation and imitation in the human brain. *NeuroImage*, *50*(3), 1148–1167. https://doi.org/10.1016/j.neuroimage.2009.12.112

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Erlbaum.

Colton, J., Bach, P., Whalley, B., & Mitchell, C. (2018). Intention insertion: Activating an action's perceptual consequences is sufficient to induce non-willed motor behavior. *Journal of Experimental Psychology: General*, *147*(8), 1256–1263. https://doi.org/10.1037/xge0000435

Cracco, E., Bardi, L., Desmet, C., Genschow, O., Rigoni, D., De Coster, L., Radkova, I., Deschrijver, E., & Brass, M. (2018). Automatic Imitation: A meta-analysis. *Psychological Bulletin*, *144*(5), 453–500. https://doi.org/10.1037/bul0000143

Cracco, E., Braem, S., & Brass, M. (2020, October 26). Observing conflicting actions elicits conflict adaptation. Retrieved from https://osf.io/ubntz/.

Cracco, E., & Brass, M. (2018a). Automatic imitation of multiple agents: Simultaneous or random representation? *Journal of Experimental Psychology: Human Perception & Performance*, *44*(5), 729–740. https://doi.org/10.1037/xhp0000489

Cracco, E., & Brass, M. (2018b). Motor Simulation of Multiple Observed Actions. *Cognition*, *180*, 200–205. https://doi.org/10.1016/j.cognition.2018.07.007

Cracco, E., & Brass, M. (2018c). The role of sensorimotor processes in social group contagion. *Cognitive Psychology*, *103*, 23–41.

Cracco, E., & Cooper, R. P. (2019). Automatic imitation of multiple agents: A computational model. *Cognitive Psychology*, *113*, 101224. https://doi.org/10.1016/j.cogpsych.2019.101224

Cracco, E., De Coster, L., Andres, M., & Brass, M. (2015). Motor simulation beyond the dyad: Automatic imitation of multiple actors. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(6), 1488–1501. https://doi.org/10.1037/a0039737

Cracco, E., De Coster, L., Andres, M., & Brass, M. (2016). Mirroring multiple agents: Motor resonance during action observation is modulated by the number of agents. *Social Cognitive and Affective Neuroscience*, *11*(9), 1422–1427. https://doi.org/10.1093/scan/nsw059

Cracco, E., Keysers, C., Clauwaert, A., & Brass, M. (2019). Representing Multiple Observed Actions in the Motor System. *Cerebral Cortex*, *29*(8), 3631–3641. https://doi.org/10.1093/cercor/bhy237

de Leeuw, J. R., & Motz, B. A. (2016). Psychophysics in a Web browser? Comparing response times collected with JavaScript and Psychophysics Toolbox in a visual search task. *Behavior Research Methods*, *48*(1), 1–12. https://doi.org/10.3758/s13428-015-0567-2

Dignath, D., Johannsen, L., Hommel, B., & Kiesel, A. (2019). Reconciling cognitive-control and episodic-retrieval accounts of sequential conflict modulation: Binding of control-states into event-files. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(9), 1265–1270. https://doi.org/10.1037/xhp0000673

Duthoo, W., Abrahamse, E. L., Braem, S., Boehler, C. N., & Notebaert, W. (2014). The heterogeneous world of congruency sequence effects: An update. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01001

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *7*(4), 380–390. https://doi.org/10.3758/CABN.7.4.380

Egner, T. (2014). Creatures of habit (and control): A multi-level learning perspective on the modulation of congruency effects. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01247

Fox, N. A., Bakermans-Kranenburg, M. J., Yoo, K. H., Bowman, L. C., Cannon, E. N., Vanderwert, R. E., Ferrari, P. F., & van IJzendoorn, M. H. (2016). Assessing human mirror activity with EEG mu rhythm: A meta-analysis. *Psychological Bulletin*, *142*(3), 291–313. https://doi.org/10.1037/bul0000031

Freund, M., & Nozari, N. (2018). Is adaptive control in language production mediated by learning? *Cognition*, *176*, 107–130. https://doi.org/10.1016/j.cognition.2018.03.009

Gallup, A. C., Hale, J. J., Sumpter, D. J. T., Garnier, S., Kacelnik, A., Krebs, J. R., & Couzin, I. D. (2012). Visual attention and the acquisition of information in human crowds. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(19), 7245–7250. https://doi.org/10.1073/pnas.1116141109

Garcea, F. E., Stoll, H., & Buxbaum, L. J. (2019). Reduced competition between tool action neighbors in left hemisphere stroke. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior, 120*, 269–283. https://doi.org/10.1016/j.cortex.2019.05.021

Gazzola, V., & Keysers, C. (2009). The observation and execution of actions share motor and somatosensory voxels in all tested subjects: Single-subject analyses of unsmoothed fMRI data. *Cerebral Cortex*, *19*(6), 1239–1255. https://doi.org/10.1093/cercor/bhn181

Giner-Sorolla, R. (2018, January 24). Powering Your Interaction. *Approaching Significance*. https://approachingblog.wordpress.com/2018/01/24/powering-your-interaction-2/

Grant, L. D., Cookson, S. L., & Weissman, D. H. (2020). Task sets serve as boundaries for the congruency sequence effect. *Journal of Experimental Psychology: Human Perception and Performance*, *46*(8), 798–812. https://doi.org/10.1037/xhp0000750

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the Use of Information: Strategic Control of Activation of Responses. *Journal of Experimental Psychology: General*, *121*(4), 480–506.

Greenwald, A. G. (1970). Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. *Psychological Review*, *77*(2), 73–99. https://doi.org/10.1037/h0028689

Gronau, Q. F., Ly, A., & Wagenmakers, E.-J. (2020). Informed Bayesian t-Tests. *The American Statistician*, *74*(2), 137–143. https://doi.org/10.1080/00031305.2018.1562983

Hedges, L. V., & Vevea, J. L. (1998). Fixed-and Random-Effects Models in Meta-Analysis. *Psychological Methods*, *3*(4), 486–504. https://doi.org/10.1037/1082-989X.3.4.486

Hommel, B. (2009). Action control according to TEC (theory of event coding). *Psychological Research*, *73*(4), 512–526. https://doi.org/10.1007/s00426-009-0234-2

Jeffreys, H. (1961). *Theory of Probability* (3rd ed.). Oxford University Press.

Kan, I. P., Teubner-Rhodes, S., Drummey, A. B., Nutile, L., Krupa, L., & Novick, J. M. (2013). To adapt or not to adapt: The question of domain-general cognitive control. *Cognition*, *129*(3), 637–651. https://doi.org/10.1016/j.cognition.2013.09.001

Kleiman, T., Hassin, R. R., & Trope, Y. (2014). The control-freak mind: Stereotypical biases are eliminated following conflict-activated cognitive control. *Journal of Experimental Psychology: General*, *143*(2), 498–503. https://doi.org/10.1037/a0033047

Latane, B. (1981). The Psychology of Social Impact. *American Psychologist*, *36*(4), 1–14. https://doi.org/10.1037/0003-066X.36.4.343

Lee, C.-I., Mirman, D., & Buxbaum, L. J. (2014). Abnormal dynamics of activation of object use information in apraxia: Evidence from eyetracking. *Neuropsychologia*, *59*, 13–26. https://doi.org/10.1016/j.neuropsychologia.2014.04.004

Milgram, S., Bickman, L., & Berkowitz, L. (1969). Note on the drawing power of crowds of different size. *Journal of Personality and Social Psychology*, *13*(2), 79–82. https://doi.org/10.1037/h0028070

Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorials in Quantitative Methods for Psychology*, *4*(2), 61–64. https://doi.org/10.3758/s13414-012-0291-2

Myung, J., Blumstein, S. E., Yee, E., Sedivy, J. C., Thompson-Schill, S. L., & Buxbaum, L. J. (2010). Impaired access to manipulation features in Apraxia: Evidence from eyetracking and semantic judgment tasks. *Brain and Language*, *112*(2), 101–112. https://doi.org/10.1016/j.bandl.2009.12.003

Naish, K. R., Houston-Price, C., Bremner, A. J., & Holmes, N. P. (2014). Effects of action observation on corticospinal excitability: Muscle specificity, direction, and timing of the mirror response. *Neuropsychologia*, *64*, 331–348. https://doi.org/10.1016/j.neuropsychologia.2014.09.034

Notebaert, W., & Verguts, T. (2008). Cognitive control acts locally. *Cognition*, *106*(2), 1071–1080. https://doi.org/10.1016/j.cognition.2007.04.011

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203.

Poldrack, R. A. (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Sciences*, *10*(2), 59–63. https://doi.org/10.1016/j.tics.2005.12.004

Prinz, W. (1997). Perception and Action Planning. *European Journal of Cognitive Psychology*, *9*(2), 129–154.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin*, *86*(3), 446–461. https://doi.org/10.1037/0033-2909.86.3.446

Ridderinkhof, K. R., Ullsperger, M., Crone, E. a, & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science*, *306*(2004), 443–447. https://doi.org/10.1126/science.1100301

Scherbaum, S., Fischer, R., Dshemuchadse, M., & Goschke, T. (2011). The dynamics of cognitive control: Evidence for within-trial conflict adaptation from frequency-tagged EEG. *Psychophysiology*, *48*(5), 591–600. https://doi.org/10.1111/j.1469-8986.2010.01137.x

Scherbaum, S., Frisch, S., & Dshemuchadse, M. (2016). Switches of stimulus tagging frequencies interact with the conflict-driven control of selective attention, but not with inhibitory control. *International Journal of Psychophysiology*, *99*, 103–107. https://doi.org/10.1016/j.ijpsycho.2015.11.012

Schmidt, J. R. (2013). Questioning conflict adaptation: Proportion congruent and Gratton effects reconsidered. *Psychonomic Bulletin & Review*, *20*(4), 615–630. https://doi.org/10.3758/s13423-012-0373-0

Shackman, A. J., Salomons, T. V., Slagter, H. A., Fox, A. S., Winter, J. J., & Davidson, R. J. (2011). The integration of negative affect, pain and cognitive control in the cingulate cortex. *Nature Reviews Neuroscience*, *12*(3), 154–167. https://doi.org/10.1038/nrn2994

Shamay-Tsoory, S. G., Saporta, N., Marton-Alper, I. Z., & Gvirts, H. Z. (2019). Herding Brains: A Core Neural Mechanism for Social Alignment. *Trends in Cognitive Sciences*, *23*(3), 174–186. https://doi.org/10.1016/j.tics.2019.01.002

Shin, Y. K., Proctor, R. W., & Capaldi, E. J. (2010). A Review of Contemporary Ideomotor Theory. *Psychological Bulletin*, *136*(6), 943–974. https://doi.org/10.1037/a0020541

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662.

Vassena, E., Holroyd, C. B., & Alexander, W. H. (2017). Computational Models of Anterior Cingulate Cortex: At the Crossroads between Prediction and Effort. *Frontiers in Neuroscience*, *11*, 316. https://doi.org/10.3389/fnins.2017.00316

Verbruggen, F., Notebaert, W., Liefooghe, B., & Vandierendonck, A. (2006). Stimulus- and response-conflict-induced cognitive control in the flanker task. *Psychonomic Bulletin & Review*, *13*(2), 328–333. https://doi.org/10.3758/BF03193852

Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control: Dealing with specific and nonspecific adaptation. *Psychological Review*, *115*(2), 518–525. https://doi.org/10.1037/0033-295X.115.2.518

Verguts, T., & Notebaert, W. (2009). Adaptation by binding: A learning account of cognitive control. *Trends in Cognitive Sciences*, *13*(6), 252–257. https://doi.org/10.1016/j.tics.2009.02.007

Vermeylen, L., Wisniewski, D., González-García, C., Hoofs, V., Notebaert, W., & Braem, S. (2020). Shared Neural Representations of Cognitive Conflict and Negative Affect in the Medial Frontal Cortex. *Journal of Neuroscience*, *40*(45), 8715–8725. https://doi.org/10.1523/JNEUROSCI.1744-20.2020

Watson, C. E., & Buxbaum, L. J. (2015). A distributed network critical for selecting among tool-directed actions. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *65*, 65–82. https://doi.org/10.1016/j.cortex.2015.01.007

Weissman, D. H., Egner, T., Hawks, Z., & Link, J. (2015). The congruency sequence effect emerges when the distracter precedes the target. *Acta Psychologica*, *156*, 8–21. https://doi.org/10.1016/j.actpsy.2015.01.003

Weissman, D. H., Jiang, J., & Egner, T. (2014). Determinants of congruency sequence effects without learning and memory confounds. *Journal of Experimental Psychology: Human Perception and Performance*, *40*(5), 2022–2037. https://doi.org/10.1037/a0037454

Wendelken, C., Ditterich, J., Bunge, S. a, & Carter, C. S. (2009). Stimulus and response conflict processing during perceptual decision making. *Cognitive, Affective & Behavioral Neuroscience*, *9*(4), 434–447. https://doi.org/10.3758/CABN.9.4.434

Supplementary Material

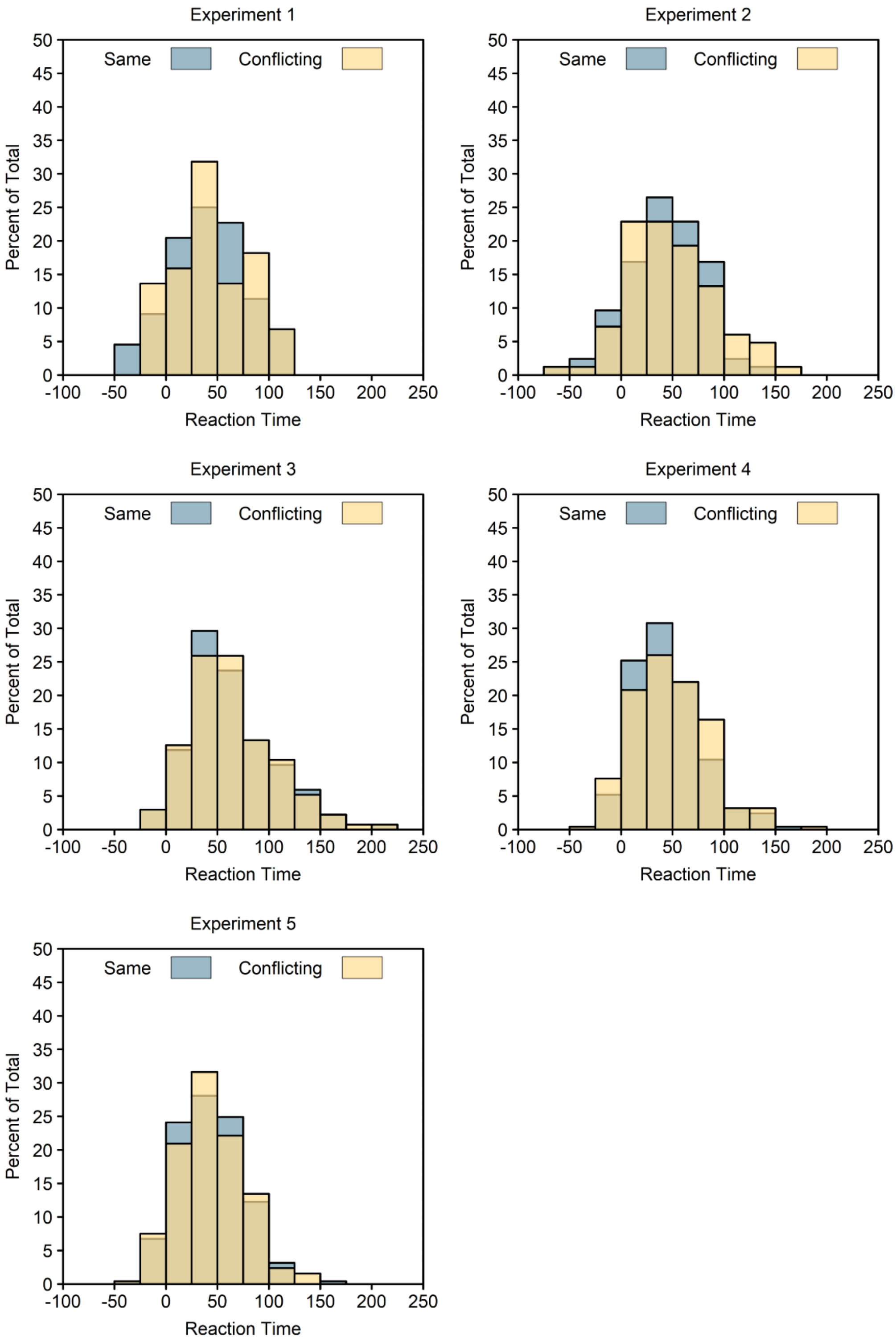

Figure S1. Distribution of the reaction time congruency effects in each of the four experiments.

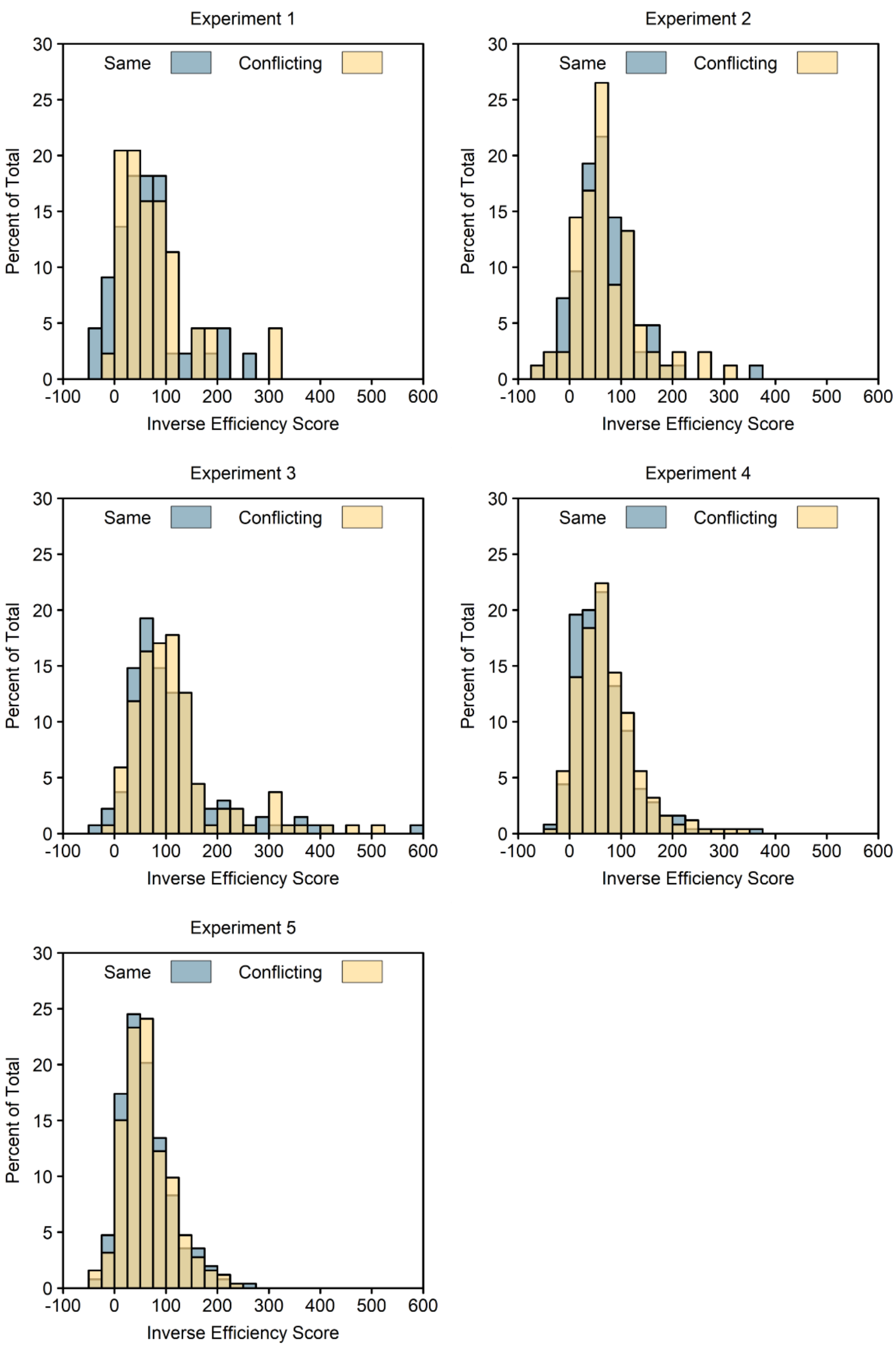

Figure S2. Distribution of the inverse efficiency score congruency effects in each of the four experiments.

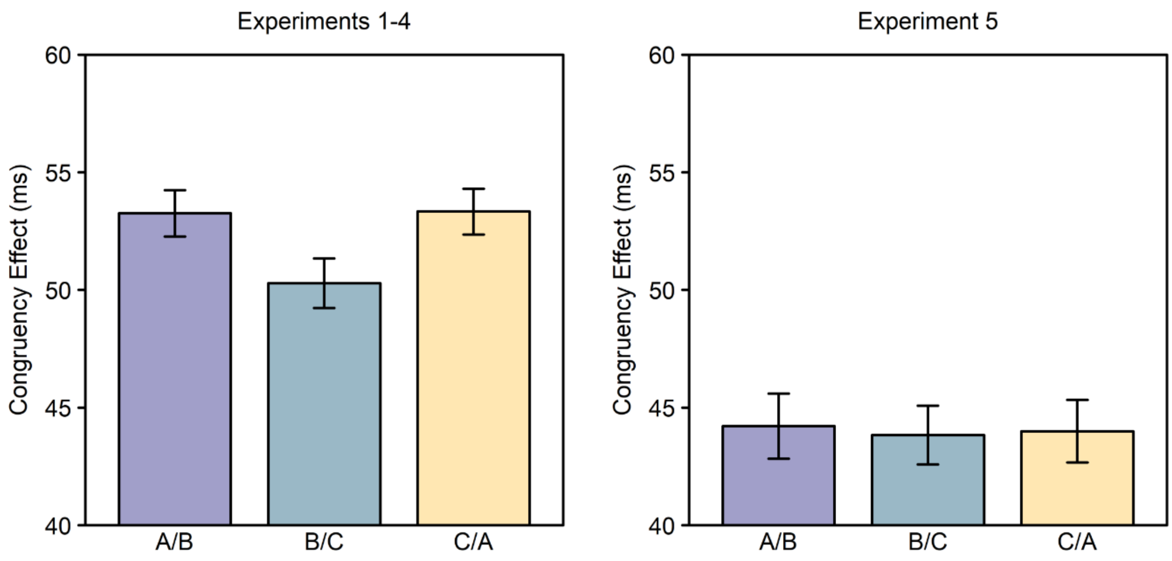

Figure S3. Reaction time congruency effects for the different combinations of conflicting gestures. See Figure 1 in the paper for which gesture corresponds to which letter. As can be seen there, B and C are similar to each other but dissimilar to A. In Experiments 1-4, the congruency effect is weaker for B/C than for A/B and C/A (see main paper). In Experiment 5, this is not the case. Error bars are SEMs corrected for within-subject designs according to Morey (2008).