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Action monitoring boosts perceptual confidence

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Author Contributions: R.S, K.D, T.G, A.D designed research; R.S and A.D performed research; R.S, T.G, A.D analyzed data; R.S, T.G, A.D wrote the paper.

Competing Interest Statement: We declare no competing interest.

Classification: Biological Sciences, Psychological and Cognitive Sciences

Keywords: confidence, decision-making, action monitoring, EEG

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Abstract

Dominant models of metacognition argue that the quality of sensory information determines perceptual confidence. However, recent accounts suggest that also motor signals contribute to confidence judgments. In line with this assumption, we conducted three pre-registered experiments to investigate the role of the motor preparation of perceptual decisions on confidence. Participants reported the orientation of a Gabor and indicated the level of confidence in their response. A visual cue, displayed before the Gabor, induced the planning of an action that could be congruent/incongruent with the response side and compatible/incompatible with the effector subsequently used to report the Gabor's orientation. In the three experiments, we observed that confidence consistently increased when participants prepared spatially incongruent actions compared to congruent actions, irrespectively of the effector primed and independently of the correctness of their responses. In the third experiment, electroencephalography recordings (EEG) showed increased P2 amplitude for incongruent compared to congruent actions, suggesting that the planning of incongruent actions led to a larger involvement of early attentional resources required for response inhibition which in turn impacted post-decisional markers of confidence (Error Positivity). Taken together, these findings suggest that motor information might trigger action monitoring mechanisms susceptible to

alter confidence in our decisions, implying that motor processes are not only the output, but also an input of the decision process.

Significance Statement

While virtually every decision we make leads to an action, the role of motor processes in decision making has been largely neglected. Our results show that retrospective confidence in a perceptual discrimination task is boosted when the motor execution is spatially incongruent with motor preparation, independently of the correctness of the response. Electroencephalography recordings indicate that this effect could be explained by a larger involvement of early attentional resources related to action monitoring, which has an impact on confidence computations. Taken together, these results suggest that motor processes might trigger action monitoring mechanisms susceptible to alter retrospective confidence in our decisions, implying that motor processes are not only the output, but also an input of the decision mechanisms.

Main Text

Introduction

In a world where feedback is sparse and uncertain, adaptive behavior crucially relies on the ability to estimate the accuracy of our perceptual representations and decisions (Mamassian, 2016). The sense of confidence therefore plays a prominent role in learning (Guggenmos et al. 2016), information seeking (Desender et al. 2018), social interactions (Bahrami et al. 2010), and might be altered by some neurological and psychiatric pathologies (Rouault et al. 2018). Delineating the factors influencing the formation of confidence is therefore crucial for the understanding of adaptive behavior (Rahnev et al. 2021).

Perceptual confidence is typically measured and dissociated from accuracy by asking participants to provide two types of responses while they complete a perceptual decision task. Firstly, they provide a perceptual decision over a stimulus (e.g., they indicate whether a Gabor patch is vertically or horizontally oriented). This decision is generally implemented by an action such as a button-press. Then, they judge on a scale how confident they are that their perceptual decision was correct. Due to the tight relationship between accuracy and confidence, dominant models of metacognition argue that perceptual confidence is determined by the quality of sensory information, i.e., confidence increases with the strength of perceptual evidence (Galvin et al. 2003; Kiani & Shadlen, 2009; Vickers, 1979). However, motor signals associated with the perceptual decision have also been shown to influence confidence estimations, over and above perceptual evidence. For instance, effortful motor responses to a perceptual stimulus inflate confidence (Turner et al. 2021). Similarly, confidence increases when perceptual decisions are preceded by partial motor activations revealed by electromyography (Gajdos et al. 2019), and when preceded by responses given to a different task (Siedlecka et al. 2020). Moreover, confidence is more accurate when perceptual decisions are reported through a motor response rather than when they are not (Pereira et al. 2020; Siedlecka et al. 2021). It has also been shown that transcranial magnetic stimulation over premotor areas after stimulus presentation modulates confidence (Fleming et al. 2015). Taken together, these findings suggest that besides sensory evidence, motor signals linked to the perceptual decision modulate confidence judgments.

However, it remains unclear what specific aspect of motor processing (i.e., motor preparation or motor execution processes) is responsible for this modulation, and how it takes place. To tackle these issues, we conducted three pre-registered experiments aiming specifically at investigating whether and how motor preparation of perceptual responses modulates confidence estimations. Participants reported the orientation of a Gabor (vertical or horizontal) with their index fingers and judged their confidence in their decision. A visual cue priming an action was displayed before the Gabor to induce the preparation of the chosen or unchosen perceptual response. Specifically, the primed action could involve the *same* or a *different* effector (feet in Experiment 1; middle fingers in Experiment 2) than the one used to report the Gabor, and could also be spatially *congruent* or *incongruent* with the perceptual response. This two-by-two design allowed us to disentangle the impact of effector-specific and more global spatial components of motor preparation on

confidence. In Experiment 3, in which only spatial congruency was manipulated, we used electroencephalography (EEG) to investigate the specific brain processes modulating confidence.

Regarding the question of how the motor system contributes to perceptual confidence, two accounts can be proposed each providing distinct predictions. Previous research showed that evidence accumulation occurs in the motor circuits associated with the effector used to bring about perceptual decisions (Shadlen et al. 2015; 2021). Accordingly, by facilitating the preparation of a given motor response one may facilitate the process of evidence accumulation and in turn influence confidence judgments. In line with this idea, it has been suggested that fluent actions lead to higher confidence judgments compared to non-fluent actions (Fleming et al. 2015). Accordingly, this account would predict an increase in confidence when the action prime facilitates the preparation of the *chosen* perceptual response. Alternately, it has been proposed that action monitoring processes are strongly involved in confidence computations (Yeung & Summerfield 2012). This is corroborated by studies showing that the Prefrontal Cortex plays a critical role in both perceptual confidence and the monitoring of self-generated decisions (Tsujimoto et al. 2010; Fleming et al. 2012). According to this framework, confidence estimates would not only be influenced by the fluency of action preparation, but also by whether alternative and unwanted responses have successfully been controlled and inhibited (Gajdos et al. 2019; Anzulewicz et al. 2019). Accordingly, this account would predict that confidence increases when the action primed is in conflict with the subsequently chosen perceptual response, since in this condition the system would have successfully inhibited and controlled unwanted responses (Gajdos et al. 2019).

In the three experiments we consistently observed that confidence increased when participants prepared spatially incongruent compared to spatially congruent actions, irrespectively of the effector primed. Importantly, this effect was independent of perceptual accuracy. These results are compatible with the hypothesis that action monitoring processes play a role in the formation of confidence. Specifically, confidence was higher in incongruent trials because motor processes successfully controlled and overcame misleading motor preparation (Gajdos et al. 2019). Consistently, Event Related Potentials (ERPs) analyses and in particular changes in the P2 component suggested that the preparation of incongruent actions led to a larger involvement of attentional resources required for response inhibition which in turn impacted post-decisional markers of confidence (Error Positivity). Taken together, these findings suggest that confidence computations are in part driven by how well individuals monitor and control their actions, independently of their perception of sensory information. In other words, the more one is in control of their responses the more they will be confident in their decisions.

Importantly, these results shed light on the more general issue of the role of the motor system in cognition. While virtually every decision we make leads to an action, motor processes largely remain the "Cinderella of psychology" (Rosenbaum, 2005). Classically, motor processes are considered as mere auxiliary components of decision-making, without interest from the cognitive point of view, i.e., their only role is to implement a decision (Pylyshyn, 1984). In most decision-making models, motor execution is treated as a nuisance parameter. Such is the case, for instance, in the celebrated drift diffusion model (Ratcliff, 1978). In line with recent research showing that motor processes are tightly linked to decision-making (e.g., Kiani & Shadlen 2009; McKinstry et al. 2008), our results demonstrate that higher cognition processes such as metacognition are also intimately linked to motor processes. More precisely, they suggest that motor information might trigger control mechanisms susceptible to alter confidence in our decisions, implying that motor processes are not only the output, but also an input of the decision mechanisms.

Results

Behavioral Results

Data were analyzed in R (R Core Team 2021) using mixed-effects models available in the lme4 package (Bates et al. 2015). The results were replicated using Bayesian analyses as implemented in the Brms package (Bürkner, 2017) and with the inclusion of all outliers (see Materials and Methods for details). Response times

(RT) were calculated with respect to the onset of the Gabor patch. Complete results are presented in Table 1, 2, and 3.

Confidence.
We observed a main effect of spatial congruency, with higher confidence in incongruent than congruent trials (Experiment 1: odd-ratio = 0.94, $p = 0.004$; Experiment 2: odd-ratio = 0.94, $p = 0.017$; Experiment 3: odd-ratio = 0.90, $p < 0.001$, see Fig. 1D and Table 1). There was no effect of effector compatibility on confidence (Experiment 1: $p = 0.78$; Experiment 2: $p = 0.67$), and no significant interaction between spatial congruency and effector compatibility (Experiment 1: $p = 0.22$; Experiment 2: $p = 0.26$; Experiment 3: $p = 0.19$, see Table 1). Accordingly, priming the side of an action seemed sufficient to modulate confidence, over and above the specific effector primed.

Accuracy.
No effect of spatial congruency on accuracy was observed in Experiment 1 ($p = 0.88$) and Experiment 2 ($p = 0.1$). Incongruent responses were slightly more accurate (M = 0.74, se = 0.09) than congruent responses (M = 0.72, se = 0.09) in Experiment 3 (odd-ratio = 0.92, $p = 0.02$, Fig. 1C and Table 2). In Experiment 2 we found an effect of effector compatibility on accuracy (odd-ratio = 1.13, $p < 0.001$), with lower accuracy when the visual cue primed feet responses (M = 0.64, se = 0.12) compared to hand responses (M = 0.71, se = 0.11). This effect was not observed in Experiment 2 ($p = 0.68$). Finally, there was no significant interaction between congruency and effector (Experiment 1: $p = 0.80$; Experiment 2: $p = 0.92$, see Table 2). The effect of congruency on confidence was present even when we controlled for accuracy and RT in the model. Accordingly, it cannot be attributed to a change in accuracy for incongruent compared to congruent trials.

Response time.
No effect of spatial congruency on RT was observed in Experiment 1 ($p = 0.14$, Fig. 1B and Table 3). However, RTs were faster for congruent (Experiment 2: M = 696 ms, se = 22 ms; Experiment 3: M = 696 ms, se = 22 ms) than incongruent trials (Experiment 2: M = 713 ms, se = 18 ms; Experiment 3: M = 713 ms, se = 18 ms) in Experiment 2 ($\beta = -7.8$, $p = 0.004$) and Experiment 3 ($\beta = -14.76$, $p < 0.001$, see Fig. 1B and Table 3).

ERP Results (Exp. 3)
P300. As a sanity-check we investigated the link between confidence and the stimulus-locked P300 component. Previous research has often linked the parietal P300 to evidence accumulation, sensory uncertainty, and confidence judgments (Polich, 2007; Twomey et al. 2015; Herding et al. 2019). Consistently, we observed that confidence was correlated with the amplitude of the P300 from 350 to 500 ms at Pz, with higher confidence judgments associated with higher P3 amplitudes ($F(23) = 3.59$, $p = 0.03$, Fig. 2A).
Lateralized Readiness Potentials (LRP). We investigated whether our motor priming paradigm influenced the temporal dynamics of the motor activity through the LRP component. Response-locked LRP were calculated using the double subtraction process (Material & Methods; Coles, 1989). Jackknifed-based analysis of the response-locked LRP using a one-third threshold revealed that congruent LRP onset latencies started slightly earlier (interpolated estimate = -184 ms) compared to incongruent LRP onset latencies (interpolated estimate = -157 ms), hence revealing a significant difference in onset latency (D = 27.2 ms, sd = 7.2, $t(23) = 3.77$, $p < 0.01$, Fig. 2B). Taken together, these findings and the behavioral effect of congruency on response times (cf. Experiments 2 and 3) suggest that our motor priming task successfully induced the preparation of motor responses prior to the presentation of the Gabor.
Error Positivity (Pe). The Pe is an event-related component, classically found at parietal electrode Pz, exhibiting a positive amplitude after incorrect choices and it is regarded as a robust measure of individuals' ability to monitor their mistakes in decision-making tasks (Falkenstein et al. 1991; Davies et al. 2001). Recent studies showed that confidence judgment also strongly correlates with the Pe (Boldt et al. 2015), the lower the confidence (or higher the certainty of making an error), the more positive the Pe. Accordingly, we investigated whether congruency influenced this component, in order to highlight the specific process that spatial congruency modulated. Firstly, we performed a cluster-based permutation test comparing congruent and incongruent EEG epochs going from 0 to 500 ms post-response. This analysis identified two significant post-response temporal clusters (Fig. 2C), one going from 70 ms to 240 ms (earlier than the classical Pe) and

another one from 260 ms to 320 ms, which corresponds to the classical Pe time window (Boldt et al. 2015). Subsequently, we binned the four confidence levels into low confidence (levels 1 and 2) and high confidence (levels 3 and 4) trials. To investigate interactions between confidence and congruency, we then performed a 2 (congruency: congruent vs. incongruent) by 2 (confidence: high vs. low) repeated-measures ANOVA on the amplitude of the post-responses ERP observed at each temporal cluster. The analyses on the 'early Pe' (i.e., from 70 to 240 ms) showed a main effect of congruency ($F(23) = 10.66$, $p = 0.003$, Fig. 2C), with a more negative Pe for incongruent compared to congruent trials. Within this time window neither the main effect of confidence nor the interaction was significant ($F(23) = 0.03$, $p = 0.86$ and $F(23) = 0.25$, $p = 0.62$, respectively). With the classical Pe window (i.e., from 260 to 320 ms) we observed a main effect of congruency ($F(23) = 8.71$, $p = 0.007$) and of confidence ($F(23) = 5.05$, $p = 0.03$, Fig. 2C). The Pe was more negative for incongruent compared to congruent, and for high compared to low confidence trials. No significant congruency and confidence interaction was observed ($F(23) = 0.37$, $p = 0.55$). Since there was a small behavioral effect of congruency on accuracy, we performed the same tests on correct trials only and we observed similar results (SI Appendix).

P200. To investigate the way action preparation may have influenced confidence judgment we analyzed whether congruency modulated EEG markers of cognitive control and early attentional resource allocation that have been studied in go/no-go tasks at mid-frontal electrodes Fz, FCz, and Cz (Folstein et al. 2008; D'angiulli et al. 2012), such as the P2 component (Luck et al. 2012; Ghin et al. 2021). Indeed, in our experiments the action prepared in response to the visual cue could have been in conflict with the action required to report the orientation of the Gabor (i.e., incongruent trials). Specifically, preparing a congruent action in advance may have facilitated response selection, while preparing an incongruent action may have led the participant to control and inhibit unwanted choices as soon as the Gabor was presented. Hence, we hypothesized that this conflict would be observed rather early after the onset of the Gabor. Accordingly, we investigated the temporal dynamics of brain activity after Gabor onset to identify differences between congruent and incongruent trials. Specifically, a cluster-based permutation test performed on a time windows going from 0 ms to 350 ms post-stimulus onset (i.e., we selected a time window in which no perceptual response could have already occurred), identified a significant temporal cluster at FCz ($t(23) = -2.6$, $p < 0.05$, Fig. 2D) going from 190 to 240 ms (similar results for Fz and Cz, see SI Appendix), i.e., in a time period where the P2 component is typically observed (Ghin et al. 2022). Specifically, the amplitude of the P2 was higher for incongruent compared to congruent trials. Since there was a small effect of congruency on accuracy, we performed the same tests on correct trials only, which yielded to similar results (SI Appendix).

Discussion

The aim of this study was to investigate whether and how motor preparation modulates retrospective confidence in perceptual decisions. In three experiments, 64 participants performed a perceptual task and then indicated their confidence regarding the accuracy of their response. To manipulate the preparation of perceptual responses we designed a motor priming paradigm. Participants reported the orientation of a Gabor (vertical or horizontal) with their index fingers and judged their confidence in their decision. A visual cue priming an action was displayed before the Gabor to induce the preparation of the chosen or unchosen perceptual response. The primed action could involve the *same* or a *different* effector (feet in Experiment 1; middle fingers in Experiment 2) than the one used to report the Gabor, and could also be spatially *congruent* or *incongruent* with the perceptual response.

Accordingly, this novel design allowed us to study the impact of effector-specific and more global spatial components of motor preparation on confidence. In Experiment 3, in which only spatial congruency was manipulated, we used electroencephalography (EEG) to investigate the specific brain processes modulating confidence.

In Experiment 2 and 3, responses were faster in congruent compared to incongruent trials. Consistently, the latency of the Lateralized Readiness Potentials (LRP) waveform (Experiment 3) was on average 27 ms shorter for congruent than for incongruent responses (Fig.1B). LRP are thought to reflect the preparation of motor activity (Kornhuber & Deecke, 1965; Schmitz et al. 2019). Taken together, these observations confirmed that we successfully manipulated the selection/preparation of perceptual responses.

In all three experiments, we observed that our manipulation induced consistent effects on confidence above and beyond perceptual accuracy. While controlling for accuracy and response time (see Fig. 1 and Table 1), trial-by-trial analysis revealed that participants were more confident in their decision when their response was incongruent with the primed action. This effect was general and independent of whether we primed the same (index fingers) or a different effector (feet in Experiment 1, and middle fingers in Experiment 2) with respect to the effector used in the perceptual task. This change of confidence was also observed irrespectively of the correctness of the response, suggesting that congruency induced a confidence bias rather than a change in metacognitive efficacy. The fact that confidence judgments were consistently modulated by spatial congruency suggest that early action preparation processes involving the spatial representation of an upcoming action were particularly involved in the confidence modulation we observed. Indeed, spatial information can be common between different effectors due to the partial overlap of spatial and semantic codes associated to different actions (Fournier et al. 2010; Wiediger & Fournier, 2008).

The analysis of EEG recordings collected in Experiment 3 confirmed these results. Specifically, the Error-Positivity (Pe) component, which occurs around 300 ms after a perceptual response and is maximal at centro-parietal sites, covaries with confidence ratings (Boldt & Yeung, 2015), and it is thought to reflect post-decisional evidence accumulation (Desander et al. 2021). In accordance with our behavioral results, we found that the Pe was modulated by both congruency and confidence (Fig. 2C). Interestingly, we also observed a modulation of the response-locked EEG activity from 70 ms to 240 ms after the response. This modulation was only driven by congruency and not by confidence, suggesting that congruency by itself impacted early post-response processes. We speculate that while the Pe is associated with the accumulation of sensory evidence (Orr & Carrasco, 2011; Desander et al. 2021) and its evaluation (Boldt & Yeung, 2015), this early post-response ERP may reflect an early evaluation of the motor response. Notably, it may indicate the successful control of unwanted motor impulse (e.g., the control of an incongruent motor plan).

The observed confidence boost in incongruent trials is in agreement with a recent study showing that perceptual responses preceded by partial motor activations (either ipsilateral or contralateral) are systematically associated with higher confidence (Gajdos et al. 2019). It has been suggested that partial motor activations reflect premature commitments to a response that are successfully controlled and inhibited, thus resulting in higher confidence in the final decision due to a greater sense of control, in line with recent studies showing that response competition triggers cognitive control mechanisms (Desender et al. 2014; Questienne et al. 2018, 2021). A similar mechanism might be at work when the response is incongruent with respect to the previously planned action. Notably, observers were more confident in their decisions because they successfully controlled unwanted motor plans. Stimulus-locked EEG recorded in Experiment 3 provides additional arguments in favor of this explanation. Specifically, the P2 component of the stimulus-locked EEG is thought to reflect early attentional resource allocation (Crowley & Colrain, 2004; Xie et al. 2020) associated with cognitive control (Ghin et al. 2022), sensitive to an early updating process during task-switching (Capizzi et al. 2015), and related to inhibitory processing (Smith et al. 2004), with a higher P2 for successful inhibition (Senderecka et al. 2012). Our analyses revealed that the P2 component was significantly modulated by congruency (Fig. 2D), with higher amplitude in incongruent compared to congruent trials. We argue that the preparation of incongruent actions led to a larger involvement of early attentional resources required for response inhibition which in turn influenced confidence and post-decisional markers of confidence (see above). Interestingly, a recent study suggested that TMS pulses to the dorsolateral prefrontal cortex (dlPFC) as early as 200 ms after stimulus onset affect confidence, suggesting a broad window for confidence computations beginning before the perceptual decision has been fully made, and providing evidence against strong versions of post-decisional models of confidence where confidence is exclusively computed on signals arriving after the decision has been made (Xue et al. 2023). This explanation would also account for the discrepancy between the results presented here and those obtained by stimulating premotor areas (Fleming et al. 2015). It has been shown that TMS stimulation over premotor areas associated with a chosen perceptual response (congruent stimulation) boosts confidence, whereas incongruent stimulation decreases confidence (Fleming et al. 2015). Crucially, this effect is observed when the stimulation occurs either before or after the response. It is therefore very unlikely that the incongruency of the stimulation triggers action monitoring mechanism. On the contrary, it is likely that TMS stimulation of the premotor

areas modulates the motor representations associated with the responses, and thereby impact confidence computations.

In summary, our results show that motor processes contribute, beyond and over perceptual evidence, to the formation of retrospective perceptual confidence. Specifically, confidence is not only modulated by fluency of action selection and preparation (Fleming et al. 2015). Action-monitoring systems are also strongly involved in confidence computations (Yeung & Summerfield 2012; Pereira et al. 2020). According to this framework, the system continuously monitors sensory and motor information, and what influence confidence estimates would not only be action fluency, but also how well the system inhibits and controls alternative and unwanted responses (Gajdos et al. 2019; Anzulewicz et al. 2019). This study thereby demonstrates that motor processes are not merely ancillary processes allowing to implement decisions, but actively contributes to the formation of high-level cognitive constructs such as retrospective confidence.

Materials and Methods

The experimental paradigm and the analysis plan for the three experiments were pre-registered prior to data collection using the Open Science Framework (https://osf.io/z6v9y/).

Materials.

Participants. For Experiment 1, data collection was interrupted after gathering the data from 16 participants that did not violate our data inclusion criteria (see SI Appendix). This sample size was estimated by performing a statistical power analysis (using G*Power; Faul et al. 2007), based on a pilot study that investigated the effect of our motor priming paradigm on response times (see OSF pre-registration: MG1). Ten participants were not included in the sample since they did not fulfill our inclusion criteria (see SI Appendix). The remaining 16 participants (11 females, mean age = 24.9, SD = 4.18) were analyzed. Based on the results of the first experiment (see OSF pre-registration: MG2) and on the decision to increase statistical power, the data collection of Experiment 2 was interrupted after gathering the data from 24 participants. In total 32 adults were recruited for this experiment, 8 of them were not included in the sample since they did not fulfill our inclusion criteria (see SI Appendix). The remaining 24 participants (14 females, average age = 25.8, SD = 3.68) were analyzed. For Experiment 3, we replicated the procedure of Experiment 2 (see OSF pre-registration: MG3) and no participant was excluded, hence 24 participants (12 females, average age = 25.4, SD = 4.36) were recruited for this experiment and included in the analyses. Participants were paid 10€/hour in gift card (and 15€/hour for Experiment 3 since it involved EEG). All participants had normal or corrected-to-normal vision, were right-handed, and were naïve regarding the hypothesis under investigation. They all gave written and informed consent before participating in the experiment. This study was conducted in agreement with the requirements of the Declaration of Helsinki and approved by the ethics committee of Université Paris Descartes (authorization n.2018-87).

Equipment. Participants performed the experiment in a dark room. They were comfortably seating in front of a 20-inch LCD monitor (Asus PG248Q with 1920 by 1080 screen resolution) with a refresh rate of 60 Hz. The experiment was programmed with Python (Python Software Foundation. Python Language Reference, version 3.9. Available at http://www.python.org) and the stimuli were generated using the Psychopy software (Peirce et al. 2019). A button response box (Millikey Response Box MH-5) and foot pedals (Accuratus X3P Footswitch) were used to collect participants' hand and feet responses, respectively. For Experiment 3, two thumb-press buttons were specifically built for convenience (SI Appendix). EEG signals were recorded with 64 Ag/AgC1 electrodes mounted on an elastic cap and amplified by an ActiCHamp Plus amplifier (Brain Products GmbH, Munich, Germany). Electrodes were arranged according to the international 10–20 systems. EEG data were online referenced to M2. EEG signal was sampled at a digitization rate of 500 Hz.

Methods.

Experimental paradigm. In the three experiments, we manipulated the motor preparation of perceptual responses, by randomly interleaving the trials of a perceptual task with the trials of a speeded Reaction Time (RT) task. In each trial (of both the perceptual and the speeded RT task) a visual cue was displayed (e.g., an arrow in Experiment 2 and 3, see below). The visual cue indicated the action to perform (e.g., left or right key-press) in the speeded RT task. This action had to be executed as soon as a white flash was presented.

However, in part of the trials, participants rather than viewing a white flash, were presented with a near-threshold Gabor. In those trials, they were instructed to ignore the speeded RT task and to perform instead a perceptual task, which consisted in indicating the orientation of the Gabor. Crucially, the task to perform at each trial was not known at the time of the cue onset, i.e., only the presentation of the white-flash or the Gabor indicated the participant what task to perform. We expected that the presentation of the visual cue would push the participants to prepare in advance a response in order to meet the temporal constraint imposed by the speeded RT task. The action preparation induced by the cue would then facilitate (or interfere with) the execution of a compatible (or incompatible) action required to report the orientation of the Gabor.

Experiment 1

Each trial started with a presentation of a green fixation cross (0.4° by 0.4°, degrees of visual angle, dva) at the center of the screen for a duration of 300 ms. A visual cue was then displayed for 200 ms. The cue was the same fixation cross but presented with a different color (e.g., blue or yellow). In the **speeded RT task** trials participants were instructed to respond to report the color of the cue by executing a left or a right response as soon as a white flash (1.8° diameter) was displayed (e.g., left-response if the fixation turned blue and right-response if the fixation turned yellow). In half of the trials, participants reported the color of the fixation with their index fingers (the same pair of effectors used in the perceptual task described below, i.e., same effector block), while in the other half of the trials, they reported the color by using their feet (different effector block).

The white flash was presented 800 ms after the onset of the cue and displayed for a duration of 48 ms. Participants had 800 ms to respond to the cue. If no response was given within this delay, the trial was interrupted and a message 'too late!' was displayed. The action-color mapping and the order of the blocks (same and different effector) were counterbalanced across participants.

In one third of the trials, rather than viewing a white flash, participants were presented with a noise texture (1.8° diameter) for 50 ms. A Gabor patch (1.8° diameter) was then displayed 800 ms after the onset of the noise stimulus, for a duration of 50 ms. In these trials, participants were instructed to forget about the speeded RT task and were asked to perform a **perceptual task** instead. Importantly, perceptual and speeded RT trials were randomly interleaved. The perceptual task consisted in discriminating the orientation (horizontal or vertical) of the Gabor patch. The Gabor was embedded in a noisy texture and displayed with a contrast level supporting 72.5% correct discrimination performance calculated separately for each participant in a preliminary calibration phase (SI Appendix). Perceptual responses were provided by executing a left or right index finger key-press as quickly and as accurately as possible (Gabor-response mapping was counterbalanced across participants). Participants had 800 ms to respond. If no response was given within this delay, the trial was interrupted with an error message and added to the trial list.

Critically, the action performed to report the orientation of the Gabor could be compatible or incompatible with the action prepared to report the visual cue. In particular, we manipulated two sorts of compatibilities. Firstly, the action prepared to report the cue could be spatially congruent or incongruent with the response selected to report the Gabor. For instance, in spatially incongruent trials, the cue induced the preparation of a left (index finger or foot) response while the participant performed a right (index finger) response to report the Gabor. Secondly, the action prepared to report the cue could involve the same (index fingers) or a different pair of effectors (feet) than those used by the participant to report the Gabor. Hence, the experiment implemented a 2 by 2 factorial design with *Spatial congruency* (congruent and incongruent) and *Effector compatibility* (same and different).

After the perceptual response, participants reported their confidence on a scale from 1 to 4 corresponding to the probability that their perceptual decision was correct (1: guessing, 2: barely confident, 3: fairly confident, 4: certainly correct). The confidence level numbers were displayed inside four circles randomly displayed around the center of the screen (Fig. 1A). There was no time pressure to report confidence ratings. To indicate the level of confidence at each trial, since participants used four effectors in the experiment, each of the four effectors were associated with a confidence circle (see Fig. 1A).

The experiment lasted about one hour and thirty minutes and was divided into two main blocks (same and different effector block). Each block was composed of 11 mini-blocks of 36 trials each (24 cue and 12 Gabor

task trials) for a total of 792 trials evenly split into 22 blocks. Before the main experiment, a training phase and a calibration phase were performed (SI Appendix.).

Experiment 2

For Experiment 2, we made a few changes to the design of Experiment 1. In order to make the speeded RT task easier and more intuitive, the visual cue was a white arrow (1° by 1°) displayed at the center of the screen pointing either to the left or to the right. Participants were instructed to indicate its direction with a left or right response respectively (Fig. 1A, SI Appendix). Furthermore, in the *different effector* block we replaced left and right foot responses with left and right middle finger button-presses. We changed the effectors because in Experiment 1 we observed a clear deterioration of performances when switching from lower- to upper-limb actions. Since the speeded RT task was easier, it enabled us to bring the onset of the Gabor patch closer to the cue. Hence, we removed the warning noise texture presented before the occurrence of the Gabor, which was now displayed 800 ms after the cue.

We also increased the response time limit of the perceptual task to 1500 ms. Additionally, in case participants made an involuntary mistake in the perceptual task (i.e., they executed a right key-press but they wanted to perform a left key-press), they could report it during the confidence judgment (Fig. 1A). These trials (6.0 %, i.e., 290 errors over 4800 trials in total) were omitted from further analysis. Participants reported 151 errors in the different effector condition (44 in the incongruent and 107 in the congruent condition) and 139 in the same effector condition (52 in the incongruent and 87 in the congruent condition).

The experiment lasted ~45 minutes and was divided into two main blocks (same effector and different effector). Each block was composed of 5 mini-blocks of 40 trials each (20 cue and 20 Gabor trials) for a total of 400 trials evenly split into 10 blocks.

Experiment 3

In Experiment 3, the design was identical to Experiment 2, except for the following changes. Since effector compatibility did not seem to impact confidence, we removed the different effector condition, so the speeded RT task was always performed with the index fingers as for the perceptual task. Participants indicated their confidence by moving an arrow pointing towards one of the confidence levels. Participants could move the arrow either clockwise (right hand) or anti-clockwise (left hand) and validated their confidence level with a double button-press (SI Appendix). Additionally, the confidence display was presented 1.25 seconds after the perceptual response to leave some time without visual stimulation for EEG considerations.

The experiment was divided into 10 mini-blocks of 40 trials each (20 cue and 20 Gabor trials) for a total of 400 trials lasting about 45 minutes. As for Experiment 2 participants could report involuntary conscious errors. These trials (4.0 %, i.e., 207 error over 4800 trials in total) were omitted from further analysis. Specifically, participants reported 133 errors for congruent and 74 for incongruent trials.

Data analyses.

Behavioral data. Data were analyzed using R (R Core Team, 2020). We used Linear Mixed-effects models from the package lme4 (Bates et al. 2015) and Cumulative link models for ordinal regression from the package ordinal (Christensen et al. 2018). All regressions were performed with the restricted maximum likelihood fitting method, and *p*-values for coefficients were obtained with the lmerTest package (Kuznetsova et al. 2017). The models were adjusted to accommodate convergence or singularity issues. The structure of random effects was determined based on the parsimony principle (Bates et al. 2015). For some analyses, the inclusion of the maximal random structure led to convergence failures. In those cases, we performed a Principal Component Analysis (PCA) to isolate the random effects that the least contributed to model fitting and we removed them one-by-one from the final model, until there were no convergence failures. We used an alpha level of 0.05 for all statistical tests. Factors were coded using sum contrasts, and response times were centered (with respect to the across-subjects mean). In addition, our results were replicated with the inclusion of outliers (SI Appendix) and they were also replicated using Bayesian methods implemented with the Brms package in R (Bürkner, 2017; SI Appendix). For graphical representations, the package ggplot2 was used (Wickham, 2009).

EEG Data. EEG data were analyzed using MNE-Python 1.3.0 (Gramfort et al. 2013, 2014) and re-referenced to the left and right mastoids (M1 and M2). The signal was band-pass filtered between 0.05 and 48 Hz by a non-causal infinite impulse response filter. The raw data was inspected visually to remove time periods containing large artifacts. Subsequently, we performed an independent component analysis (Hyvärinen, 1999), to identify and remove components representing blinks or eye movements. We then extracted epochs going from -1900 ms to 2500 ms time-locked to Gabor onset. A second artifact rejection was performed. Epochs containing amplitudes greater than 100 µV or less than -100 µV were marked as potential artifacts and then removed after confirmation through visual inspection. This led to the removal of 224 out of 4628 trials, i.e. a proportion of 0.048. From the remaining epochs we extracted response-locked segments starting from 1500 ms before and ending 900 ms after the perceptual response. EEG activity in specific time windows for ERP components was quantified through mean amplitudes calculation and tested with ANOVA and t-tests as it is robust to different numbers of trials across conditions (Luck, 2014). If no specific time windows were identified from the literature for a component, we performed a nonparametric cluster-based permutation test (Maris and Oostenveld, 2007) to isolate the time windows exhibiting a difference between congruent and incongruent trials.

To investigate the temporal dynamics of the motor responses, we focused on the lateralized readiness potentials (LRP). LRPs were calculated using the double subtraction method, where the average effector-specific activity over the left and right motor cortices (electrodes C3 and C4) are subtracted (Coles, 1989). Gabor-locked LRP epochs were corrected with a baseline of 200 ms preceding the onset of the visual cue in order to observe potential motor activity induced by the cue prior to Gabor onset; and between -1000 and -800 ms for the response-locked LRP (Kraemer & Gluth, 2023). To investigate potential differences in the onset latency of LRP components observed in congruent and incongruent trials, a jackknife-based method with a one-third threshold was used (Miller et al. 1998; Ulrich & Miller, 2001) on response-locked epochs with a time window starting from 800 ms before the response until the response (Smulders & Miller, 2012) as it is a powerful method for analyzing LRP onset latencies which is used in most studies that were published after its introduction. To analyze the Pe component, response-locked epochs were corrected with a 100 ms baseline, going from -100 to 0 ms prior to the response (Boldt & Yeung., 2015), and the period of interest was 250-350 ms post-response at Pz as this time window and electrode were already identified in previous study of EEG correlates of confidence (Wang et al. 2020; Boldt and Yeung., 2015). More recent studies suggested that the Pe could also extend over a longer time window (Rausch et al. 2020). Since it was the case in the present study, cluster-based permutation tests on the difference between congruent and incongruent between 0 ms to 500 ms post-response at Pz revealed another temporal cluster (see Results), from 70 ms to 240 ms post-responses. To investigate the interaction between congruency and confidence, we binned the four levels of confidence into low (confidence ratings equal 1 or 2) and high (confidence ratings equal 3 or 4) trials. Data were then analyzed with repeated-measure ANOVAs on the amplitude of the post-response ERPs observed in the two time periods reported above. Finally, to identify temporal clusters that would suggest which ERP component is of interest in the N1/P2/N2 complex, we used a cluster-based permutation test comparing the ERP amplitude observed in congruent and incongruent trials on a time window going from 0 to 350 ms post-stimulus at electrode Fz, Cz and FCz with a baseline of 200 ms prior to Gabor onset (Folstein & Van Petten, 2008; Luck et al. 2012).

Acknowledgments

This research was funded by the Agence Nationale de la Recherche, research funding ANR JCJC, project number ANR-18-CE10-0001, awarded to Andrea Desantis. We would like also to thank Steve Fleming for his comments and suggestions on this research.

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Figures and Tables

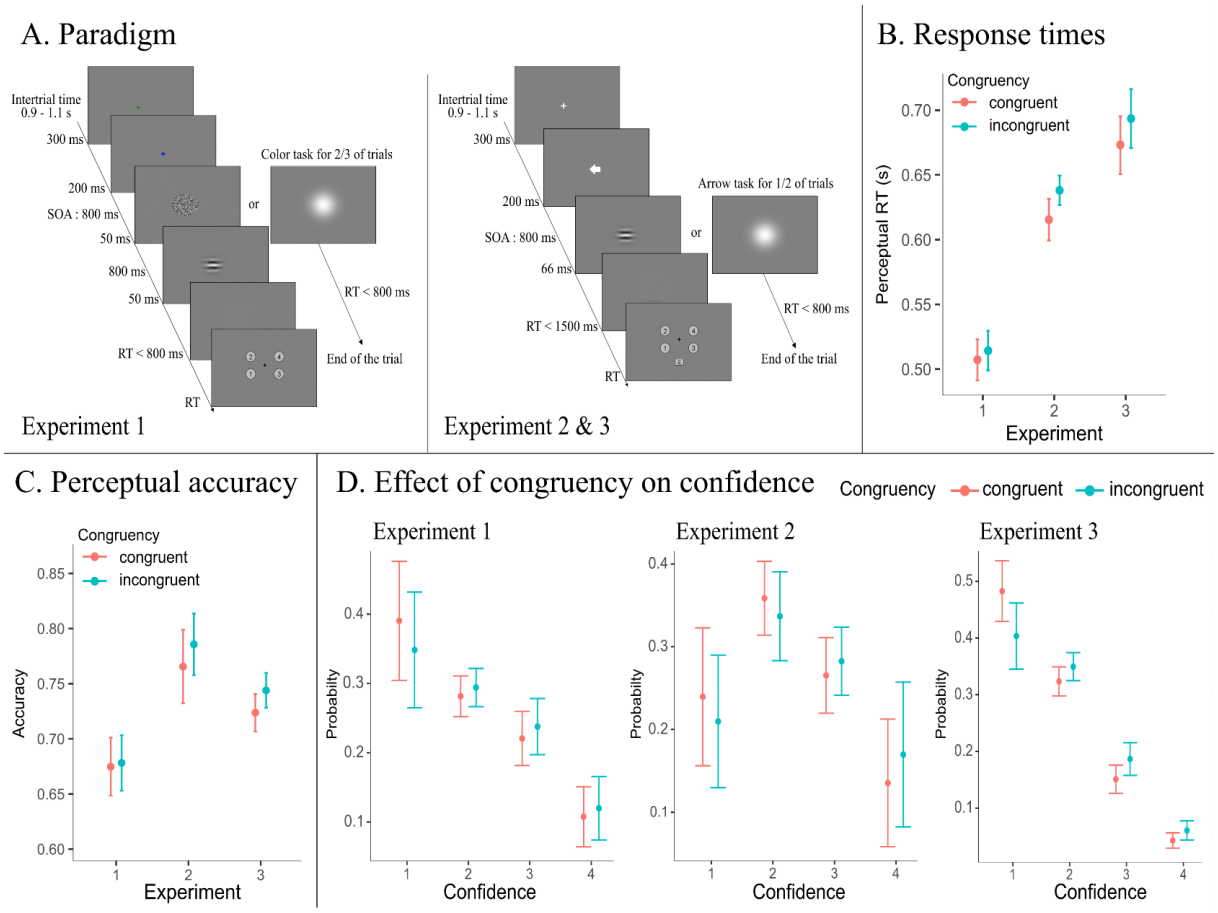

Figure 1. Experimental paradigm and behavioral results. *(A)* Experimental paradigm : A participant sees a cue at the beginning of each trial indicating a left or right response, and then, randomly, either the participant is presented with a white flash and has to perform a left or right button-press based on the cue (speeded motor task), or either the participant is presented with a noise patch followed by a noisy Gabor patch (Exp. 1) or directly a noisy Gabor patch (Exp 2 & 3) and has to perform a left or right button-press based on the orientation of the Gabor patch (horizontal or vertical, speeded perceptual task), and subsequently reports confidence in the perceptual decision. Congruency is defined by the motor correspondence between the side of the response indicated by the cue and the actual side of the perceptual response. *(B)* Average response times for the perceptual task for congruent (red) and incongruent (blue) trials for Exp 1, 2, & 3. Error bars represent standard errors. *(C)* Average accuracy for the perceptual task for congruent (red) and incongruent (blue) trials for Exp 1, 2, & 3. Error bars represent standard errors. *(D)* Cumulative Link Mixed Model predicting confidence probabilities as a function of congruency (congruent: red, incongruent: blue) for Exp. 1, 2, & 3. The error bars represent standard errors.

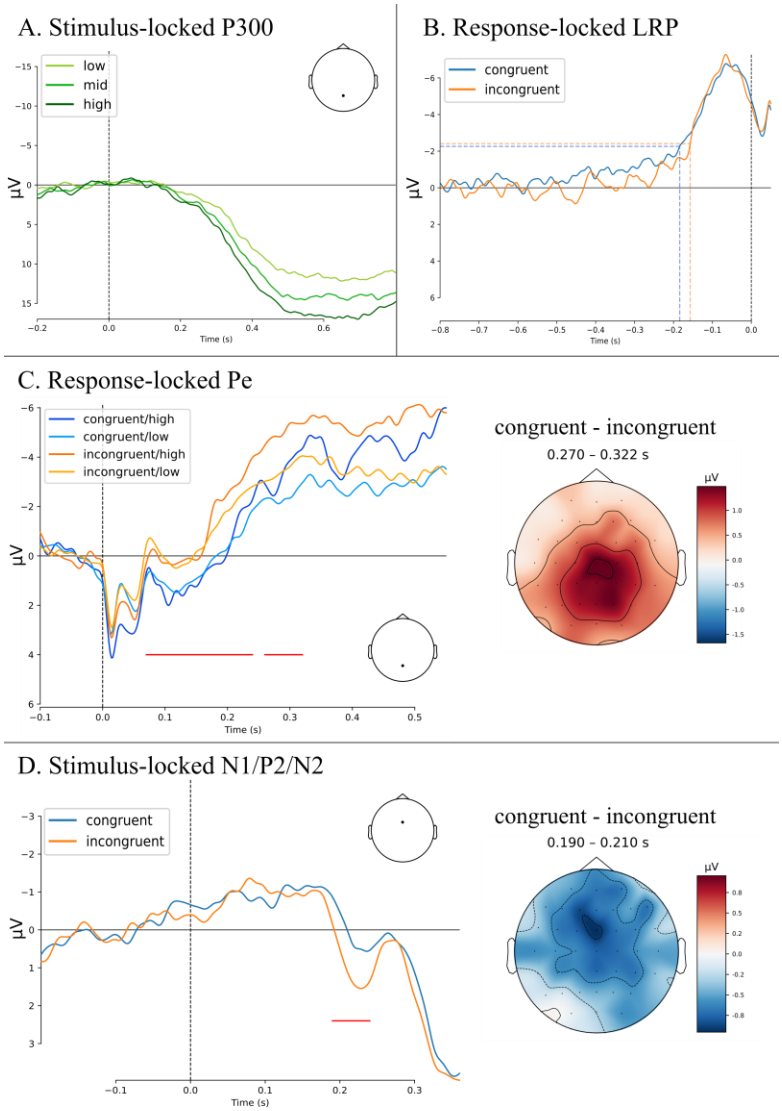

Figure 2. Grand averaged Event-Related Potentials. *(A)* Stimulus-locked P300 : ERP at Pz to the onset of the perceptual response (vertical dotted line) for low (1), mid (2), and high (3 & 4) confidence levels. *(B)* Response-locked Lateralized Readiness Potential : ERP of LRP (double subtraction method, between C3 and C4) of the congruent (red line) and incongruent (blue line) trials prior to the onset of the perceptual response (vertical dotted black line). The colored dotted lines represent the LRP onset latency at 1/3 threshold of the peak amplitude for congruent (blue) and incongruent (red) trials extracted from a Jackknife-based procedure showing a significant difference of 27 ms in LRP onset latency. *(C, Left)* Response-locked Pe : ERP at Pz to the onset of the perceptual response (vertical dotted line) for the congruent (red lines) and incongruent (blue lines) trials for low (light) and high (dark) confidence. Confidence level 1 and 2 were binned into Low, and confidence level 3 and 4 were binned into High. Red horizontal lines represent significant temporal clusters from a permutation test on the difference between congruent and incongruent trials. These clusters were used to investigate the interaction between congruency and confidence on Pe activity with ANOVAs. *(C, Right)* Voltage difference topography between congruent and incongruent trials averaged across the time window of the second cluster. *(D, Left)* Stimulus-locked N1/P2/N2 complex : ERP at FCz to the onset of the perceptual stimulus (vertical dotted line) for the congruent (red line) and incongruent (blue line) trials. Red horizontal line represents significant temporal clusters from a permutation test on the difference between congruent and incongruent trials. *(D, Right)* Voltage difference topography between congruent and incongruent trials averaged across the time window of the cluster.

Table 1. Hierarchical regression tables predicting confidence from accuracy, congruency, and reaction time for Experiment 3 (right), plus effector and effector order for Experiment 1 (left) and 2 (middle). Predictors were coded as follows: Accuracy: error = -1, correct = 1; Congruency: incongruent = -1, congruent = 1; Effector compatibility: different effector (feet in Experiment 1, middle fingers in Experiment 2) = -1, same effector (index fingers) = 1; Bloc order: same effector first = -1, different effector first = 1. Response time is mean-centered.

	Confidence (Exp. 1)			**Confidence (Exp. 2)**			**Confidence (Exp. 3)**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
1|2	0.66	0.50 – 0.86	**0.002**	0.43	0.31 – 0.60	**<0.001**	0.85	0.74 – 0.99	**0.037**
2|3	1.66	1.27 – 2.17	**<0.001**	1.23	0.89 – 1.70	0.209	2.36	2.03 – 2.74	**<0.001**
3|4	4.49	3.43 – 5.88	**<0.001**	3.12	2.25 – 4.32	**<0.001**	6.05	5.17 – 7.07	**<0.001**
accuracy gabor [1]	1.90	1.64 – 2.20	**<0.001**	1.42	1.32 – 1.52	**<0.001**	1.58	1.43 – 1.75	**<0.001**
congruency [1]	0.94	0.90 – 0.98	**0.004**	0.94	0.89 – 0.99	**0.017**	0.90	0.86 – 0.94	**<0.001**
effector [1]	1.01	0.94 – 1.09	0.781	0.98	0.88 – 1.09	0.668			
effector order [1]	0.78	0.61 – 0.99	**0.043**	0.74	0.54 – 1.03	0.074			
rt gabor centered	0.59	0.28 – 1.26	0.175	0.07	0.04 – 0.12	**<0.001**	0.14	0.09 – 0.22	**<0.001**
accuracy gabor [1] * congruency [1]	1.04	1.00 – 1.09	**0.028**	1.00	0.96 – 1.04	0.937	1.03	0.99 – 1.07	0.185
accuracy gabor [1] * effector [1]	1.08	1.04 – 1.13	**<0.001**	1.01	0.97 – 1.06	0.479			
congruency [1] * effector [1]	0.98	0.94 – 1.01	0.221	0.98	0.94 – 1.02	0.258			
accuracy gabor [1] * effector order [1]	0.94	0.81 – 1.09	0.396	1.03	0.96 – 1.10	0.444			
congruency [1] * effector order [1]	1.03	0.99 – 1.07	0.169	1.04	0.99 – 1.10	0.107			
effector [1] * effector order [1]	0.88	0.82 – 0.96	**0.003**	0.92	0.83 – 1.02	0.110			
(accuracy gabor [1] * congruency [1]) * effector [1]	1.02	0.98 – 1.06	0.342	1.03	0.99 – 1.07	0.127			
(accuracy gabor [1] * congruency [1]) * effector order [1]	1.00	0.96 – 1.04	0.875	0.96	0.92 – 0.99	**0.024**			
(accuracy gabor [1] * effector [1]) * effector order [1]	1.08	1.04 – 1.12	**<0.001**	1.00	0.96 – 1.04	0.926			
(congruency [1] * effector [1]) * effector order [1]	1.00	0.96 – 1.04	0.924	1.03	0.98 – 1.07	0.252			
(accuracy gabor [1] * congruency [1] * effector [1]) * effector order [1]	1.01	0.97 – 1.04	0.792	0.99	0.95 – 1.03	0.460			
Random Effects									
σ^2	1.00			1.00			1.00		
τ_{00}	$0.44_{\text{subject_id}}$			$0.35_{\text{subject_id}}$			$0.19_{\text{subject_id}}$		
τ_{11}	$0.32_{\text{subject_id.accuracy_gabor1}}$			$0.08_{\text{subject_id.accuracy_gabor1}}$			$0.20_{\text{subject_id.accuracy_gabor1}}$		
	$0.01_{\text{subject_id.congruencyincongruent}}$			$0.02_{\text{subject_id.congruencyincongruent}}$			$0.01_{\text{subject_id.congruencyincongruent}}$		
	$0.07_{\text{subject_id.effectorsame}}$			$0.25_{\text{subject_id.effectorsame}}$			$0.94_{\text{subject_id.rt_gabor_centered}}$		
	$0.54_{\text{subject_id.effector_ordersame1}}$			$1.85_{\text{subject_id.effector_ordersame1}}$					
	$1.94_{\text{subject_id.rt_gabor_centered}}$			$1.62_{\text{subject_id.rt_gabor_centered}}$					
				$0.02_{\text{subject_id.congruencyincongruent:effectorsame}}$					
ρ_{01}	-0.59			-0.20			-0.63		
	-0.43			0.35			0.52		
	-0.34			-0.33			-0.15		
	-0.33			-0.53					
	-0.73			-0.80					
				0.67					
ICC	0.39			0.32			0.24		
N	$16_{\text{subject_id}}$			$24_{\text{subject_id}}$			$24_{\text{subject_id}}$		
Observations	4224			4510			4570		
Marginal R^2 / Conditional R^2	0.216 / 0.523			0.249 / 0.486			0.222 / 0.410		

Table 2. Hierarchical regression tables predicting accuracy from congruency and reaction time for Experiment 3 (right), plus effector and effector order for Experiment 1 (left) and 2 (middle). Predictors were coded as follows: Accuracy: error = -1, correct = 1; Congruency: incongruent = -1, congruent = 1; Effector compatibility: different effector (feet in Experiment 1, middle fingers in Experiment 2) = -1, same effector (index fingers) = 1; Bloc order: same effector first = -1, different effector first = 1. Response time is mean-centered.

	Accuracy (Exp. 1)			**Accuracy (Exp. 2)**			**Accuracy (Exp. 3)**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	2.22	1.76 – 2.80	**<0.001**	3.06	2.57 – 3.64	**<0.001**	2.92	2.45 – 3.47	**<0.001**
congruency1	1.00	0.93 – 1.07	0.905	0.94	0.88 – 1.01	0.096	0.92	0.86 – 0.99	**0.021**
effector1	1.13	1.06 – 1.21	**<0.001**	0.96	0.81 – 1.15	0.690			
effector order1	1.04	0.82 – 1.31	0.769	0.92	0.77 – 1.10	0.349			
rt gabor centered	1.97	1.01 – 3.82	**0.046**	0.19	0.10 – 0.37	**<0.001**	0.23	0.14 – 0.39	**<0.001**
congruency1 * effector1	1.01	0.94 – 1.08	0.812	1.00	0.93 – 1.07	0.923			
congruency1 * effector order1	1.03	0.96 – 1.11	0.361	1.00	0.93 – 1.07	0.968			
effector1 * effector order1	1.06	0.99 – 1.14	0.089	1.12	0.93 – 1.33	0.227			
congruency1 * rt gabor centered	0.80	0.47 – 1.36	0.409	0.97	0.66 – 1.42	0.877	1.74	1.26 – 2.39	**0.001**
effector1 * rt gabor centered	0.96	0.56 – 1.64	0.887	0.95	0.62 – 1.47	0.825			
effector order1 * rt gabor centered	0.36	0.18 – 0.70	**0.003**	0.88	0.45 – 1.71	0.704			
congruency1 * effector1 * effector order1	0.99	0.92 – 1.06	0.746	0.97	0.91 – 1.04	0.450			
(congruency1 * effector1) * rt gabor centered	1.15	0.67 – 1.95	0.613	1.39	0.95 – 2.03	0.086			
(congruency1 * effector order1) * rt gabor centered	0.95	0.56 – 1.61	0.848	1.13	0.78 – 1.66	0.512			
(effector1 * effector order1) * rt gabor centered	0.94	0.55 – 1.61	0.834	0.84	0.54 – 1.29	0.424			
(congruency1 * effector1 * effector order1) * rt gabor centered	1.02	0.60 – 1.74	0.935	1.09	0.75 – 1.59	0.647			
Random Effects									
σ^2	3.29			3.29			3.29		
τ_{00}	$0.20_{\text{subject_id}}$			$0.15_{\text{subject_id}}$			$0.15_{\text{subject_id}}$		
τ_{11}	$0.43_{\text{subject_id.re1.rt_gabor_centered}}$			$0.17_{\text{subject_id.re1.effector1}}$			$0.68_{\text{subject_id.re1.rt_gabor_centered}}$		
				$1.52_{\text{subject_id.re1.rt_gabor_centered}}$					
ρ_{01}									
ρ_{01}									
ICC	0.06			0.04			0.04		
N	$16_{\text{subject_id}}$			$24_{\text{subject_id}}$			$24_{\text{subject_id}}$		
Observations	4224			4510			4570		
Marginal R^2 / Conditional R^2	0.018 / 0.075			0.035 / 0.078			0.028 / 0.071		

Table 3. Hierarchical regression tables predicting reaction time from accuracy and congruency for Experiment 3 (right), plus effector and effector order for Experiment 1 (left) and 2 (middle). Predictors were coded as follows: Accuracy: error = -1, correct = 1; Congruency: incongruent = -1, congruent = 1; Effector compatibility: different effector (feet in Experiment 1, middle fingers in Experiment 2) = -1, same effector (index fingers) = 1; Bloc order: same effector first = -1, different effector first = 1. Response time is mean-centered.

	Reaction Time (Exp. 1)			**Reaction Time (Exp. 2)**			**Reaction Time (Exp. 3)**		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-1.88	-32.52 – 28.76	0.904	10.62	-26.72 – 47.96	0.577	9.59	-35.20 – 54.37	0.675
accuracy gabor [1]	5.66	-0.03 – 11.35	0.051	-22.77	-32.43 – -13.11	**<0.001**	-23.62	-32.54 – -14.69	**<0.001**
congruency1	-2.83	-6.61 – 0.96	0.143	-7.82	-13.07 – -2.57	**0.004**	-14.76	-22.44 – -7.07	**<0.001**
effector1	4.98	-3.56 – 13.51	0.253	-9.39	-26.24 – 7.47	0.275			
effector order1	12.81	-17.83 – 43.45	0.412	18.22	-19.11 – 55.56	0.339			
accuracy gabor [1] * congruency1	-0.53	-4.30 – 3.25	0.784	-1.03	-6.27 – 4.20	0.699	9.19	3.40 – 14.99	**0.002**
accuracy gabor [1] * effector1	0.01	-3.86 – 3.88	0.995	-0.97	-6.41 – 4.47	0.728			
congruency1 * effector1	0.27	-3.51 – 4.06	0.888	1.58	-3.66 – 6.83	0.555			
accuracy gabor [1] * effector order1	-6.95	-12.64 – -1.26	**0.017**	-4.69	-14.35 – 4.97	0.341			
congruency1 * effector order1	1.13	-2.65 – 4.91	0.558	-3.97	-9.22 – 1.28	0.139			
effector1 * effector order1	-32.57	-41.11 – -24.03	**<0.001**	-4.79	-21.64 – 12.06	0.578			
accuracy gabor [1] * congruency1 * effector1	1.74	-2.04 – 5.52	0.366	1.77	-3.46 – 6.99	0.508			
accuracy gabor [1] * congruency1 * effector order1	-0.24	-4.01 – 3.54	0.901	2.27	-2.97 – 7.51	0.395			
accuracy gabor [1] * effector1 * effector order1	1.67	-2.20 – 5.54	0.397	-0.84	-6.28 – 4.60	0.762			
congruency1 * effector1 * effector order1	-1.02	-4.80 – 2.76	0.597	0.58	-4.67 – 5.82	0.829			
accuracy gabor [1] * congruency1 * effector1 * effector order1	-0.71	-4.48 – 3.07	0.714	2.69	-2.53 – 7.92	0.312			
Random Effects									
σ^2	13512.52			24257.11			30388.77		
τ_{00}	3845.82 $_{subject_id}$			7429.87 $_{subject_id}$			12309.18 $_{subject_id}$		
τ_{11}	70.96 $_{subject_id.re1.accuracy_gabor1}$			399.99 $_{subject_id.re1.accuracy_gabor1}$			281.08 $_{subject_id.re1.accuracy_gabor1}$		
	243.33 $_{subject_id.re1.effector1}$			1592.78 $_{subject_id.re1.effector1}$			160.42 $_{subject_id.re1.congruency1}$		
				1097.49 $_{subject_id.re1.effector_order1}$					
ρ_{01}									
ρ_{01}									
ICC	0.22			0.23			0.29		
N	16 $_{subject_id}$			24 $_{subject_id}$			24 $_{subject_id}$		
Observations	4224			4510			4570		
Marginal R^2 / Conditional R^2	0.069 / 0.275			0.029 / 0.257			0.013 / 0.298		