Dissociating Perception From Action During Conscious and Unconscious Conflict Adaptation

Anne Atas
Université Libre de Bruxelles

Kobe Desender
Vrije Universiteit Brussel

Wim Gevers and Axel Cleeremans
Université Libre de Bruxelles

The detection of a conflict between relevant and irrelevant information on a given trial typically results in a smaller conflict effect on the next trial. This sequential effect has been interpreted as an expression of cognitive control implemented to resolve conflict. In this context, 2 different but related issues have received increasing attention in the literature. The first issue is whether the detection of motor conflict is necessary to induce cognitive control or, alternatively, whether the detection of perceptual conflict is sufficient. The second issue concerns whether awareness of the conflict is necessary to induce cognitive control. Here, we address both issues in a single design. Our reaction-time (RT) results indicate that conflict-driven control is domain-specific. The detection of perceptual conflict on the previous trial selectively reduces perceptual conflict on the next trial. Similarly, the detection of motor conflict on the previous trial selectively reduces motor conflict on the next trial. For errors, adaptive control seemed to be more general: The detection of perceptual or motor conflict on the previous trial reduced the frequency of errors on response-conflict trials. Furthermore, unconsciously triggered conflict adaptation was observed, but not systematically. Results on errors provide some evidence that sensitivity to an unconscious conflict on the previous trial reduces the frequency of errors on the current trial. For RT analyses however, unconscious conflict appeared not to be sufficient to induce cognitive control. This pattern of results is in line with previous studies examining the role of consciousness in conflict adaptation.

Keywords: cognitive control, conflict adaptation, consciousness, perceptual conflict, motor conflict

Supplemental materials: http://dx.doi.org/10.1037/xlm0000206.supp

A central question in the study of cognitive control pertains to the mechanisms through which the cognitive system resolves conflict. Experimentally, conflict has typically been approached through paradigms such as the Stroop task, in which participants have to respond to one dimension of a stimulus (i.e., the color of a printed word) while ignoring other, potentially conflicting dimensions (i.e., the meaning of the word). Typical conflict paradigms (i.e., the Stroop task; Stroop, 1935; the Simon task; Simon & Rudell, 1967; the Erikson flanker task; Eriksen & Eriksen, 1974 and the prime–target task; Kunde & Wuhr, 2006) thus induce

cognitive conflict by contrasting task-relevant and task-irrelevant information. The main outcome from such studies is the observation that conflict modulates the speed of responding: Participant responses are slower to incongruent trials in which the task-irrelevant information is inconsistent with the task-relevant information, reflecting an interference effect. Important to note, it is also generally observed that interference effects are reduced after incongruent compared with after congruent trials. Botvinick, Braver, Barch, Carter, and Cohen (2001) interpreted this sequential effect as an expression of cognitive control. According to their

theory of conflict adaptation (see also Shenhav, Botvinick, & Cohen, 2013), conflict detection between task-relevant and task-irrelevant information in the previous trial increases cognitive control to reduce the effect of the interfering information on the current trial. A central issue within this framework is to identify what kind of conflict is susceptible to trigger an increase in cognitive control, and what kind of conflict is accordingly reduced.

Conflict may arise at different levels of processing. Conflict may involve perceptual processing, motor processing, or both (Kouider & Dehaene, 2009; Naccache, Blandin, & Dehaene, 2002). Perceptual conflict is induced when the processing of irrelevant stimulus features interferes with the processing of relevant features. Likewise, motor conflict is induced when the pre-potent response elicited by the task-irrelevant stimulus interferes with the response to the task-relevant stimulus. Although both types of conflict are generally confounded, perceptual conflict can be isolated when task-irrelevant information is perceptually different from the task-relevant information, but evokes the same response.

Within the conflict-adaptation framework, it has been proposed that the anterior cingulate cortex (ACC) detects conflict occurring between task-relevant and task-irrelevant information and specifies how to implement compensatory cognitive control adjustments. This decision is communicated to other brain areas, which implement top-down control processes and modulate task performance (Botvinic et al., 2001; Shenhav, Botvinick & Cohen, 2013). With respect to the different levels of conflict, several studies have shown activation of the ACC during response conflict, but not during perceptual conflict (Van Veen & Carter, 2002; van Veen, Cohen, Botvinick, Stenger, & Carter, 2001), whereas other studies have shown ACC activation during both perceptual and motor conflict (Nigbur, Cohen, Ridderinkhof, & Sturmer, 2012; Wendt, Heldmann, Munte, & Kluwe, 2007). With respect to the implementation of top-down control processes, a first way in which the cognitive system can achieve conflict resolution consists of modulating perceptual processing via top-down selective attention. This implies that top-down selective attention mechanisms amplify and enhance the perceptual processing of task-relevant (vs. task-irrelevant) stimuli (Botvinick et al., 2001; Cohen, Dunbar, & McClelland, 1990; Desimone & Duncan, 1995; Egner & Hirsch, 2005). A second way to implement control processes is to modulate motor processing by improving selection of task-relevant responses or by inhibiting the influence of irrelevant response activation (Egner, Delano, & Hirsch, 2007; Stürmer & Leuthold, 2003; Stürmer, Leuthold, Soetens, Schroter, & Sommer, 2002).

An important pending issue is to document how these two mechanisms—conflict detection and top-down modulation—combine at the perceptual and motor levels of processing. Previous research has demonstrated that the prime–target task can induce both perceptual and motor conflict (e.g., Kouider & Dehaene, 2009). This makes it possible to investigate which type of conflict (perceptual vs. motor) on the previous trial triggers behavioral adjustments on the current trial, and which type of conflict (perceptual vs. motor) is affected by this control. Therefore, the first main goal of the current study was to examine this issue in depth.

Apart from the specific type (i.e., perceptual, motor), conflict might also be analyzed in terms of level of consciousness. The irrelevant information that induces conflict may be perceived consciously or not. Many studies have now demonstrated that uncon-

scious primes cannot only be processed at the perceptual and motor levels (e.g., Dehaene et al., 2004; Dehaene et al., 2001; Eimer & Schlaghecken, 2003), but also afford high-level processing, such as semantic (Van den Bussche, Notebaert, & Reynvoet, 2009) or emotional processing (Naccache et al., 2005). More important to note, recent studies also demonstrated that conflict adaptation may be triggered by unconscious stimuli (Desender, Van Lierde, & Van den Bussche, 2013; Francken, Gaal, & de Lange, 2011; van Gaal, Lamme, & Ridderinkhof, 2010). It is generally assumed that high-level cognitive functions subtended by prefrontal cortex such as cognitive control can only be elicited consciously (Dehaene & Changeux, 2011). Therefore, the observation of unconsciously triggered conflict adaptation has important implications concerning our definition of consciousness. Note, however, that other researchers have failed to observe unconsciously triggered conflict adaptation (e.g., Ansorge, Fuchs, Khalid, & Kunde, 2011; Frings & Wentura, 2008), suggesting that extant conclusions about the role of unconscious stimuli in inducing cognitive control have to be taken with caution.

In this light, the aim of the present study was to determine the locus of cognitive control adaptation, both in terms of levels of processing and levels of consciousness.

To determine the locus of conflict adaptation in terms of level of processing, we mapped four arrow stimuli (i.e., up-left, down-left, up-right, and down-right arrows) onto two responses (i.e., left and right; see Figure 1B). This makes it possible to compare three levels of conflict. On identical trials, prime and target are physically identical, inducing no conflict. In stimulus-conflict trials, the prime is perceptually different from the target, but evokes the same response, thus inducing a pure perceptual conflict. Finally, in the response-conflict trials, the prime is both perceptually different from the target and evokes a different response, thus inducing both stimulus and response conflict. For the sake of simplicity, we refer to these conditions as Identical, StimConflict, and RespConflict conditions, respectively. The amount of perceptual conflict can be computed by subtracting responses to Identical trials from responses to StimConflict trials. In both cases, prime and target trigger the same response, but only in the former are they perceptually identical. Similarly, the amount of motor conflict can be assessed by subtracting responses to StimConflict trials from responses to RespConflict trials. In both cases, prime and target are perceptually different, but they evoke a different response in the latter only. Finally, the overall congruency effect can be quantified by subtracting responses to Identical trials from responses to RespConflict trials. We examine whether adaptation is driven by a perceptual conflict and/or a motor conflict experimented in the previous trial. In addition to the locus of adaptation effects on the previous trial, we also examined whether adaptive control would mainly impact perceptual and/or motor conflict on the current trial. To reliably compare our results to studies using a 2×2 stimuli/response mapping, we also examined whether the overall conflict experienced on the previous trial (Identical vs. RespConflict in Trial $n - 1$) reduced the overall congruency effect on the current trial (Identical vs. RespConflict in Trial n).

With this 4×2 stimuli/response mapping design, we also investigated the role of consciousness in conflict adaptation. To determine the locus of conflict adaptation in terms of level of consciousness, we used a metacontrast masking paradigm in Experiment 1, with either a short prime duration (i.e., 14 ms) leading
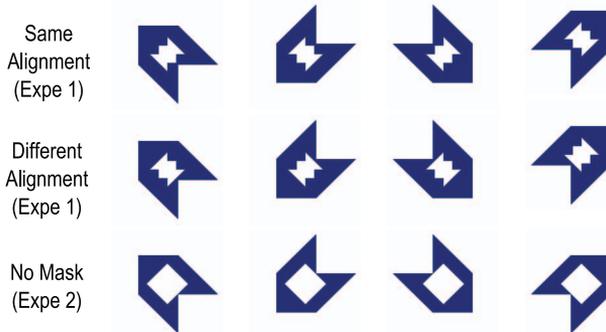
A Trial procedure

C Types of Mask-Target
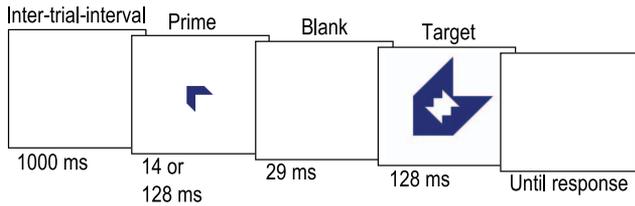
B Prime-Target relationship
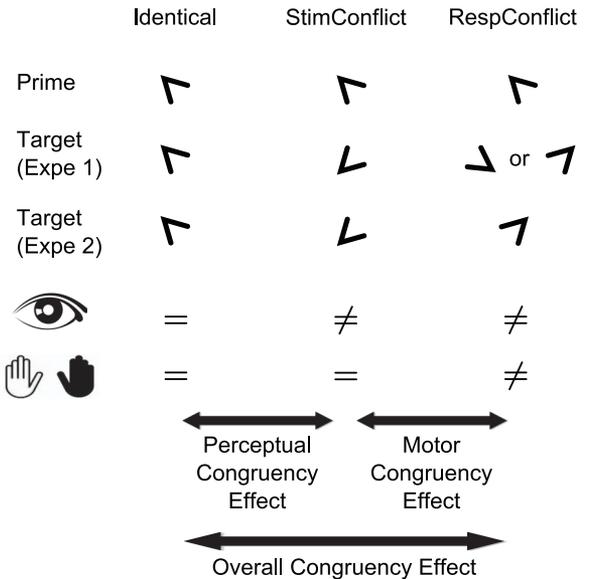
Figure 1. (A) Trial procedure of the priming task in Experiments 1 and 2. In each trial, participants had to make speeded and accurate responses with a left- or right-hand key press to the left and right orientation, respectively, of the arrow target; the prime and target stimuli were arrows pointing up-left, up-right, down-left, and down-right. In half of the trials, the prime was unconscious (14 ms), and in the other half, it was conscious (128 ms). (B) With this two-response/four-stimulus mapping, three levels of conflict between the prime and the target were compared. In the Identical trials, the prime arrow was identical to the target arrow. In the StimConflict trials, the prime arrow was visually different from the target, but they evoked the same response. In the RespConflict trials, the prime arrow was visually different from the target, and they also evoked a different response. Comparing Identical to StimConflict trials allowed extraction of the perceptual congruency effect, whereas comparing StimConflict to RespConflict trials allowed isolation of the motor congruency effect. (C) Type of Mask Target. See the online article for the color version of this figure.

to an unconscious conflict, or a long prime duration (i.e., 128 ms) leading to a conscious conflict. Most studies reporting unconscious conflict adaptation have used a 2 × 2 stimuli/response mapping (Desender et al., 2013; van Gaal et al., 2010; but see Kunde, 2003), whereas studies in which adaptation was restricted to conscious primes typically used larger stimulus sets (e.g., Ansorge et al., 2011; Frings & Wentura, 2008; Greenwald, Draine, & Abrams, 1996). If this difference is of crucial importance, it might be the case that only the overall conflict is susceptible to unconsciously triggering adaptation, whereas the more specific types may not be. If this were the case, our paradigm would be sufficiently sensitive to document the difference.

Experiment 1

Method

Participants. Fifty-one students (35 women; mean age = 21) from the Université Libre de Bruxelles participated in return for compensation of 8 euro. Participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment.

Apparatus and stimuli. Stimuli were displayed on a CRT monitor (Philips 107T). Participants viewed the screen from a distance of 70 cm. All stimuli were blue (<1 cd/m²) and displayed at the center of the screen on a white background (48 cd/m²), at 1024 × 768 resolution and a refresh rate of 70 Hz. Responses were executed with the index fingers of both hands and collected through the two extreme keys of a button box (E-prime 1.1, PST software, Pittsburgh, PA). The prime was a small up-left, down-left, up-right, or down-right pointing arrow subtending a visual angle of approximately 0.9° × 0.9° and fitting exactly into the inner contours of the mask. To improve the effectiveness of metacontrast masking, the inner contours of the mask did not correspond to the external contours of all the four possible primes. Instead, two different masks were created: one mask with inner contours corresponding to the external contours of up-left and down-right primes, and the other with inner contours corresponding to the external contours of down-left and up-right primes (see Figure 1C). The target was a large up-left, down-left, up-right, or down-right pointing arrow, subtending a visual angle of approximately 2.9° × 2°. The different arrow directions were made by tilting the stimulus less than at the angles of 45°, 135°, 225°, and

$315°$. The mask and the target were merged into the same stimulus and described as the target stimulus in the next section.

Design and Procedure. In the priming task, participants had to make speeded and accurate responses with a left- or right-hand key press to the leftward and rightward orientation of the arrow target. We used three different prime–target relationships: Identical, StimConflict, and RespConflict trials (see Figure 1B).

Each trial began with the prime being presented at the center of the screen for 14 ms or for 128 ms depending on the visibility condition. For the sake of simplicity, these conditions are labeled as unconscious and conscious, even if the 14-ms condition might turn out not to be completely unconscious. This was followed by a blank display lasting 29 ms and then by a target presented for 128 ms. Participants could respond during and after the target presentation; a blank screen was displayed until participants had responded. The intertrial interval (ITI) was another blank screen presented for 1000 ms. The experiment consisted of 12 experimental blocks of 96 trials each, separated by short breaks lasting a minimum of 30 s. Each block contained an equal number of all possible trial combinations presented in randomized order. Feedback (mean RT and percent correct) was presented after each block. Two special blocks preceded the 12 experimental blocks. The first was a "control block" of 80 trials in which the primes were not presented. This block was used to test for differences between the two masks (see Figure 1C and Supplemental materials for an analysis of mask difference). The second was a short practice block of 24 trials that contained primes and in which the six different experimental conditions were equally represented. After the 12 experimental blocks, prime visibility was evaluated through a discrimination test on the prime arrow. The display of the stimuli was identical to the main experiment, but now after the offset of the target, either the question "left?" or "right?" was displayed until participants responded, which could be done without time pressure. Participants had to respond "yes" with the left index finger if the direction of the arrow prime corresponded to the question and "no" with the right index finger if the direction of the arrow prime did not correspond to the question. The direction of the prime arrow did not correspond to the hand response to minimize the influence of automatic motor activation during the visibility task. The visibility task consisted of one block of 96 trials. Conscious and unconscious primes were randomly intermixed. All the different prime–target relations were equally represented and randomly presented.

Results

Exclusion of trials. The use of a 4×2 stimuli/response mapping makes it possible to remove complete prime–target repetitions between two consecutive trials (e.g., up-left–up-right in Trial $n-1$ followed by up-left–up-right in Trial n) from the analyses. This is important because sequential congruency effects have been previously explained in terms of repetition priming effects between consecutive trials (Mayr, Awh, & Laurey, 2003). The removal of complete repetitions from our design ruled out this potential account. Therefore, identical repetitions of prime and target between Trials $n-1$ and n (5.68%) were excluded from further analysis.[1] Trials following an error (3.71%), the first trial of each block (1.04%), and RTs <100 or >1000 (0.06%) were also

excluded from further analysis of both RTs and error rates. For the RTs analyses, errors were excluded (3.9%) as well.

Analyses on RTs. Mean RTs for correct responses were submitted to a repeated-measures ANOVA with $Congruency_n$ (Identical, StimConflict, and RespConflict), $Congruency_{n-1}$ (Identical, StimConflict, and RespConflict), $Consciousness_n$ (Conscious and Unconscious) and $Consciousness_{n-1}$ (Conscious and Unconscious) as within-subject factors. Results of this analysis are represented in Figure 2A and reported in Table S1. The main effect of $Congruency_n$ was significant, $F(2, 100) = 429.06, p < .001$. Follow-up analyses revealed both a significant perceptual congruency effect, $t(50) = 12.39, p < .001; StimConflict_n - Identical_n = 25$ ms, and a significant motor congruency effect, $t(50) = 16.74, p < .001; RespConflict_n - StimConflict_n = 46$ ms. The main effect of $Congruency_{n-1}$ was also significant, $F(2, 100) = 44.60, p < .001$. RTs in Trial n were equivalent after an $Identical_{n-1}$ and a $StimConflict_{n-1}$ (0.07 ms difference). However, RTs were 7 ms slower in Trial n after a $RespConflict_{n-1}$ than after $StimConflict_{n-1}$. The main effect of $Consciousness_n$ was also significant, $F(1, 50) = 52.05, p < .001$: Participants responded 12 ms faster to Conscious $Primes_n$ than to Unconscious $Primes_n$. Finally, the main effect of $Consciousness_{n-1}$ was also significant, $F(1, 50) = 126.82, p < .001$: Participants' responses were 10 ms slower in Trial n after a Conscious $Prime_{n-1}$ than after an Unconscious $Prime_{n-1}$.

The 2-way interaction between $Congruency_n$ and $Consciousness_n$ was also significant, $F(2, 100) = 132.40, p < .001$, indicating larger congruency effects with conscious compared with unconscious primes. Follow-up analyses showed a significant perceptual congruency effect, $t(50) = 9.71, p < .001; StimConflict_n - Identical_n = 36$ ms and motor congruency effect, $t(50) = 14.72, p < .001; RespConflict_n - StimConflict_n = 68$ ms with Conscious $Primes_n$. The same was observed with Unconscious $Primes_n$ (perceptual congruency effect, $t(50) = 13.96, p < .001; StimConflict_n - Identical_n = 15$ ms; motor congruency effect, $t(50) = 17.64, p < .001; RespConflict_n - StimConflict_n = 24$ ms), although these effects were smaller in magnitude.

More important to note, the 2-way interaction between $Congruency_n$ and $Congruency_{n-1}$ was significant, $F(4, 200) = 4.61, p = .001$, suggesting the presence of conflict adaptation. Crucially, however, this interaction was modulated by $Consciousness_{n-1}$, $F(4, 200) = 6.46, p < .001$, suggesting that the consciousness of the prime on the previous trial modulated conflict adaptation. Follow-up analyses showed that with Conscious $Primes_{n-1}$, $Congruency_n$ significantly interacted with $Congruency_{n-1}$, $F(4, 200) = 12.08, p < .001$, suggesting the presence of a conflict-adaptation effect after trials containing a conscious prime. In contrast to the significant interaction observed with conscious primes, the interaction between $Congruency_n$ and $Congruency_{n-1}$ was not significant with Unconscious $Primes_{n-1}$, $F(4, 200) = 0.73, p = .990$, suggesting that conflict adaptation fails to take place after trials containing an unconscious prime. Important to note, the absence of an interaction does not directly support the

---

[1] In this experiment, trials from the list containing 96 trials were presented randomly until the end of the list i.e., three times the 32 different prime–target couples: two consciousness conditions, four congruency conditions containing each of four different prime–target couples). This list led to 5.68% of identical repetitions.
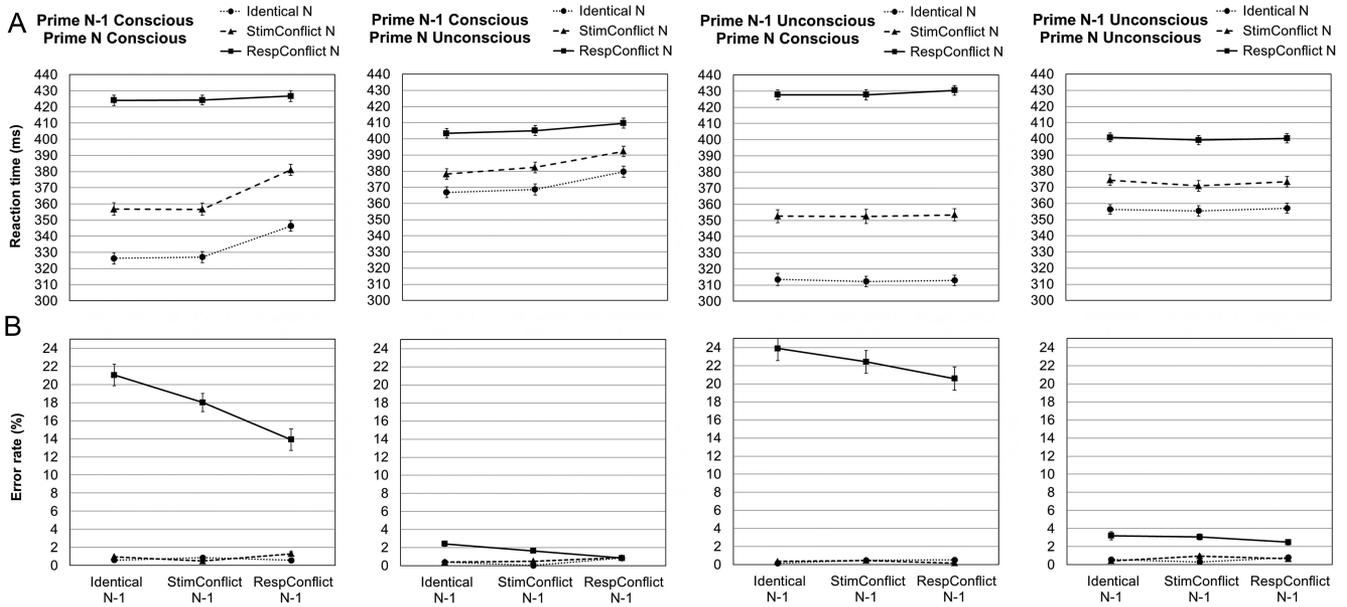
Figure 2. Results of Experiment 1: (A) mean RTs in ms and (B) mean error percentage as functions of Congruency$_n$ (Identical, StimConflict, and RespConflict on Trial n), Congruency$_{n-1}$ (Identical, StimConflict, and RespConflict, on Trial $n - 1$), Consciousness$_n$ (Conscious and Unconscious prime on Trial n), and Consciousness$_{n-1}$ (Conscious and Unconscious prime on Trial $n - 1$). Error bars represent one standard error of the mean.

absence of an unconscious adaptation effect in our data. When using the classic approach, nonsignificant p values do not tell us whether our data actually support the null hypothesis (i.e., no unconscious adaptation effect) or whether they are just insensitive with respect to this question. Therefore, as suggested by Dienes (2011), we computed a Bayes factor (BF) to interpret this null result. A BF of 1 indicates that the data are neutral with respect to our hypothesis, but BFs falling under 1/3 or above 3 are typically interpreted as offering support for the null hypothesis or for the alternative hypothesis, respectively. To compute a BF it is first necessary to specify the expected magnitude of the unconscious adaptation effect. Given that conflict adaptation might depend on the size of the conflict effect, we regressed individual overall adaptation effects from the conscious condition onto the individual congruency effects of the conscious condition. Based on the resulting equation ($y = -0.0374x + 20.804$), we computed the expected value given the mean congruency effects of the unconscious condition ($M_{predicted} = 19.16$). Subsequently, we used a half normal with $SD = 19.16$ (see Dienes, 2011). Compared with the observed difference ($M_{difference} = 1.28$, $SE = 2.59$), this resulted in a BF of 0.21. This indicates that our data provides support for the null hypothesis that there was no unconscious conflict adaptation.

The 3-way interaction between Congruency$_n$, Congruency$_{n-1}$ and Consciousness$_n$, $F(4, 200) = 1.11$, $p = .351$ and the 4-way interaction between Congruency$_n$, Congruency$_{n-1}$, Consciousness$_n$, and Consciousness$_{n-1}$, $F(4, 200) = 1.75$, $p = .141$ were not significant. Thus, neither the consciousness of the prime on the current trial nor its modulation by the consciousness of the prime in the previous trial affected adaptation to conflict.

We henceforth restricted analyses of the conflict adaptation locus in term of level of processing to conscious primes on Trial $n - 1$. The overall conflict on $n - 1$ (Identical$_{n-1}$ vs. RespConflict$_{n-1}$) significantly modulated the overall congruency effect (RespConflict$_n$ − Identical$_n$); $t(50) = 4.05$, $p < .001$; adaptation = 12 ms. The motor conflict on $n - 1$ (StimConflict$_{n-1}$ vs. RespConflict$_{n-1}$) significantly modulated the motor congruency effect (RespConflict$_n$ − StimConflict$_n$); $t(50) = 5.53$, $p < .001$; adaptation = 14 ms; whereas it did not modulate the perceptual congruency effect (StimConflict$_n$ − Identical$_n$); $t(50) = -0.82$, $p = .418$. Finally, the perceptual conflict on $n - 1$ (Identical$_{n-1}$ vs. StimConflict$_{n-1}$) did not modulate either the perceptual congruency effect or the motor congruency effect (both $ps > .630$). Again, to interpret these nonsignificant results, we computed a BF by regressing individual motor–motor adaptation effects onto the individual motor priming effects. Based on the resulting equation ($y = 0,0574x + 9,6739$), we computed the expected value for perceptually triggered adaptation ($M_{predicted} = 11.75$), and motor triggered adaptation ($M_{predicted} = 13.58$). Subsequently, we used a half normal with the corresponding value as SD. For the perceptual–perceptual adaptation effect ($M_{difference} = -0.66$, $SE = 2.19$), this led to a BF of 0.14. For the perceptual–motor adaptation effect ($M_{difference} = 1.05$, $SE = 2.18$), the BF was 0.28. Finally, for the motor–perceptual adaptation effect ($M_{difference} = -2.07$, $SE = 2.53$), the BF was 0.11. Thus, all three BFs suggested that, in the current dataset, adaptation effects were only found when motor conflict was involved. Taken together, these results suggest that adaptive control was only triggered by a motor conflict and selectively affected the motor congruency effect.

To conclude, analyses on RTs indicated perceptual and motor congruency effects in the current trial for both conscious and

unconscious primes. However, the conflict-adaptation effect was only triggered by a conscious motor conflict. Moreover, the adaptive control triggered by a conscious motor conflict selectively affected motor congruency effects (both conscious and unconscious) on the current trial.

Analyses on error rates. Subsequently, the same analysis was also performed on mean error percentages. Results of this analysis are represented in Figure 2B and reported in Table S1. The main effect of $Congruency_n$ was significant, $F(2, 100) = 70.88$, $p < .001$. The motor congruency effect was significant, $t(50) = 8.55$, $p < .001$; $RespConflict_n - StimConflict_n = 10.5\%$, but the perceptual congruency effect was not, $t(50) = 1.18$, $p = .242$; $StimConflict_n - Identical_n = 0.1\%$. Of note, errors were almost nonexistent for both Identical and StimConflict trials (0.5% and 0.6%, respectively), whereas error rate was high for RespConflict trials (11.3%). The main effect of $Congruency_{n-1}$ was also significant, $F(2, 100) = 10.88$, $p < .001$, indicating that participants made fewer errors following a conflict on $n - 1$ ($Identical_{n-1} = 4.5\%$, $StimConflict_{n-1} = 4.1\%$ and $RespConflict_{n-1} = 3.6\%$). The main effect of $Consciousness_n$ was also significant, $F(1, 50) = 86.31$, $p < .001$: Participants made 5.9% more errors to conscious primes than to unconscious primes on Trial n. Finally, the main effect of $Consciousness_{n-1}$ was also significant, $F(1, 50) = 26.64$, $p < .001$: Participants made 0.9% fewer errors in Trial n after a conscious prime on Trial $n - 1$ than after a unconscious prime on $n - 1$.

The 2-way interaction between $Congruency_n$ and $Consciousness_n$ was significant, $F(2, 100) = 81.87$, $p < .001$. Follow-up analyses revealed a significant motor congruency effect, $t(50) = 8.94$, $p < .001$; $RespConflict_n - StimConflict_n = 19.7\%$, but no perceptual congruency effect, $t(50) = -0.34$, $p = .732$; $StimConflict_n - Identical_n = 0\%$ for conscious primes on Trial n. We also found a significant motor congruency effect, $t(50) = 4.27$, $p < .001$; $RespConflict_n - StimConflict_n = 1.8\%$ and no perceptual congruency effect, $t(50) = 1.63$, $p = .110$; $StimConflict_n - Identical_n = 0.2\%$ for unconscious primes on Trial n.

More important to note, the 2-way interaction between $Congruency_n$ and $Congruency_{n-1}$ was significant, $F(4, 200) = 18.29$, $p < .001$, indicating the presence of conflict adaptation. Mirroring the RT analyses, this interaction was modulated by $Consciousness_{n-1}$, $F(4, 200) = 3.50$, $p = .009$. However, contrary to the RT results, follow-up analyses revealed significant conflict adaptation for both unconscious primes on the previous trial, $F(4, 200) = 4.17$, $p = .003$ and conscious primes on the previous trial, $F(4, 200) = 20.03$, $p < .001$. Thus, this 3-way interaction reflects stronger adaptation effects with conscious than unconscious primes on Trial $n - 1$. Furthermore, for unconscious primes on the previous trial, the overall conflict on $n - 1$ significantly modulated the overall congruency effect, $t(50) = 3.38$, $p = .001$; adaptation $= 2.32\%$, but the motor and perceptual conflict on $n - 1$ did not separately cause a reduction of the motor congruency effect ($p = .225$ and $p = .187$, respectively). In contrast, for conscious primes on the previous trial, not only the overall conflict on $n - 1$ significantly modulated the overall congruency effect, $t(50) = 5.28$, $p < .001$; adaptation $= 4.58\%$, but also both the perceptual and the motor conflict on $n - 1$ separately modulated the motor congruency effect, $t(50) = 3.02$, $p = .004$; perceptual cause of adaptation $= 1.72\%$; $t(50 = 4.37$, $p < .001$; motor cause of adaptation $= 3.06\%$). Because errors were almost nonexistent for both Identical and StimConflict trials and the perceptual congruency effect on

errors was not significant, we did not examine adaptation of the perceptual congruency effect on Trial n. To sum up, consciously triggered adaptation on errors was strong and driven by both the perceptual and motor conflicts on $n - 1$, whereas unconsciously triggered adaptation was weaker and only driven by the overall conflict.

The three-way interaction between $Congruency_n$, $Congruency_{n-1}$, and $Consciousness_n$ was also significant, $F(4, 200) = 5.58$, $p < .001$, indicating that the consciousness of the prime on the current trial modulated the conflict adaptation. More detailed analyses showed a significant adaptation effect for both unconscious primes on the current trial, $F(4, 200) = 4.28$, $p = .002$ and conscious primes on the current trial, $F(4, 200) = 13.83$, $p < .001$. The 3-way interaction suggests that the conflict adaptation was stronger when the prime in the current trial was conscious than when it was unconscious. Finally, the four-way interaction between all variables in the analysis was not significant, $F(4, 200) = 0.76$, $p = .555$.

To conclude, error-rates analysis indicated a pure motor congruency effect in the current trial for both conscious and unconscious primes. However, conscious adaptive control was triggered by both perceptual and motor conflict on the previous trial. Furthermore, we observed unconsciously triggered conflict adaptation, but it was restricted to the overall conflict.

Prime visibility. Mean accuracy of prime categorization performance was 54.3% for unconscious primes and 87.25% for the conscious primes. Mean d' values were significantly different from zero, both for unconscious primes, $d' = .23$, $t(50) = 3.33$; $p = .002$, and for conscious primes, $d' = 2.61$; $t(50) = 16.67$; $p < .001$. D' was significantly higher for conscious primes, than for unconscious primes ($t(50) = 16.72$; $p < .001$). Because we obtained robust conflict adaptation triggered by unconscious primes only on error rates for the overall contrast ($Identical_{n-1}$ vs. $RespConflict_{n-1}$ on $RespConflict_n - Identical_n$), we assessed whether this effect was dependent on the ability to discriminate unconscious primes. This effect did not correlate with our d' measure, $r(51) = -.10$, $p = .921$. We also used the regression method proposed by Greenwald, Klinger, and Schuh (1995) to test the magnitude of this conflict adaptation when performance on the prime visibility measure is extrapolated to zero. The intercept of this regression was significant, $t(50) = 3.07$, $p = .003$, intercept value $= 2.4\%$, suggesting that even when prime visibility is statistically zero, we still observed unconsciously triggered conflict adaptation on errors.

Discussion

In Experiment 1, we observed clear conflict-adaptation effects on RTs for the conscious, but not the unconscious condition. Further elaboration showed that this effect was mainly driven by motor conflict on the previous trial that influenced the size of the motor congruency effect on the current trial. Perceptual conflict on the previous trial did not seem to influence our results. In contrast, the error rates revealed both conscious and unconscious overall conflict adaptation. Moreover, in the conscious condition only, both motor conflict and perceptual conflict on the previous trial influenced the motor congruency effect on the current trial.

To dig deeper into these issues, we carried out two further experiments, in which we better controlled the level of processing

of the conflict (Experiments 2 and 3), and carried out an improved manipulation of prime visibility that controlled for temporal factors (Experiment 3).

Experiment 2

In Experiment 1, the level of processing (perceptual vs. motor) of the conflict was not perfectly controlled. Half of RespConflict trials were RespConflict 90° (e.g., the prime was a down-left pointing arrow and the target was a down-right pointing arrow), and the other half were RespConflict 180° (e.g., the prime was a down-left pointing arrow and the target was an up-right pointing arrow). Both types of RespConflict trial (90° vs. 180°) were mixed together, although there was a perceptual difference between the two (see Supplemental materials for more details about the difference). To solve this methodological issue, the RespConflict 180° condition was removed in Experiment 2. This new experiment was thus designed to dissociate the pure motor effect from the pure perceptual effect during conscious conflict adaptation. We expected to replicate previous finding with this new methodology.

Method

Twenty-nine students (22 women; mean age = 22) from the Université Libre de Bruxelles participated in return for 7 euro. Participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment. All apparatus, stimuli, design, and procedure were the same as in Experiment 1, except the following modifications. RespConflict Trial 180° and unconscious primes were removed. The target contained only a $1° \times 1°$ square metacontrast mask (see Figure 1C). Participants performed the priming task during 10 blocks of 96 trials; the first one was considered as a training block.

Results

Exclusion of trials. We excluded from the analyses of both RTs and error rates identical repetitions of prime and target between trials $n - 1$ and n $(0.6\%)^2$, trials following an error (4.44%), the first trial of each block (1.04%), and RTs <100 or >1000 (0.001%). For the RT analyses, errors were also excluded (3.7%).

Analyses on RTs. Mean RTs from correct responses were submitted to a repeated-measures ANOVA analysis with Congruency$_n$ (Identical, StimConflict, and RespConflict) and Congruency$_{n-1}$ (Identical, StimConflict, and RespConflict) as within-subject factors. Results of this analysis are presented in Figure 3. The main effect of Congruency$_n$ was significant, $F(2, 56) =$ 174.56, $p < .001$. Follow-up analyses revealed both a significant perceptual congruency effect, $t(28) = 15.35$, $p < .001$; StimConflict$_n$ − Identical$_n$ = 55 ms and a significant motor congruency effect, $t(28) = 7.78$, $p < .001$; RespConflict$_n$ − StimConflict$_n$ = 45 ms. The main effect of Congruency$_{n-1}$ was also significant, $F(2, 56) = 42.42$, $p < .001$, indicating that participants were slower on the current trial following a conflict on $n - 1$ (Identical$_{n-1}$ = 376 ms, StimConflict$_{n-1}$ = 379 ms, and RespConflict$_{n-1}$ = 386 ms). Follow-up analyses showed a significant difference both between Identical$_{n-1}$ and StimConflict$_{n-1}$, $t(28) = 2.96$, $p = .006$, and between StimConflict$_{n-1}$ and RespConflict$_{n-1}$, $t(28) = 6.43$, $p < .001$.
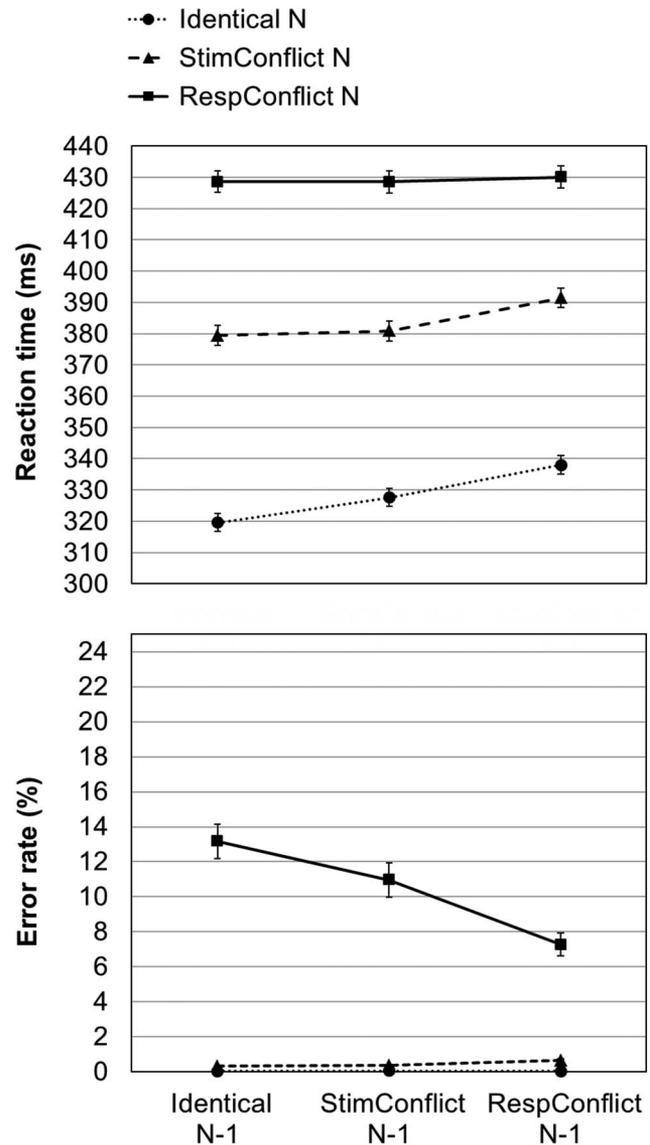
Figure 3. Results of Experiment 2: Mean RTs in millisecond and mean error percentage as function of Congruency$_n$ (Identical, StimConflict, and RespConflict on Trial n) and Congruency$_{n-1}$ (Identical, StimConflict, and RespConflict on Trial $n - 1$). Error bars represent one standard error of the mean.

The 2-way interaction between Congruency$_n$ and Congruency$_{n-1}$ was significant, $F(4, 112) = 13.24$, $p < .001$, indicating the presence of a conflict-adaptation effect. We then examined the specific cause and impact of conflict adaptation. The overall conflict on $n - 1$ (Identical$_{n-1}$ vs. RespConflict$_{n-1}$) significantly modulated the overall congruency effect (RespConflict$_n$ − Iden-

---

[2] In this experiment, trials from the list of 12 different prime–target couples (i.e., four Identical, four StimConflict 90° and four RespConflict 90° trials) were presented randomly until the end of the list. This was done eight times successively, thus avoiding almost completely the repetition of a particular couple.

tical$_n$); $t(28) = 7.29$, $p < .001$; adaptation $= 17$ ms. The motor conflict on $n − 1$ (StimConflict$_{n−1}$ vs. RespConflict$_{n−1}$) significantly impacted the motor congruency effect (RespConflict$_n$ − StimConflict$_n$); $t(28) = 3.97$, $p < .001$; adaptation $= 9$ ms; whereas it did not impact the perceptual congruency effect (StimConflict$_n$ − Identical$_n$); $t(28) = −0.07$, $p = .946$. Given an expected adaptation effect of 9 ms with motor conflict, the observed difference ($M_{\text{difference}} = −0.18$, $SE = 2.58$) produced a BF of 0.26 (using a half normal with $SD = 9$), providing evidence for the null hypothesis. Finally, the perceptual conflict on $n − 1$ (Identical$_{n−1}$ vs. StimConflict$_{n−1}$) modulated the perceptual congruency effect, $t(28) = 2.68$, $p = .012$; adaptation $= 6.5$ ms but not the motor congruency effect, $t(28) = 0.87$, $p = .392$. Here, given an expected adaptation effect of 6.5 ms with motor conflict, the observed difference ($M_{\text{difference}} = 1.47$, $SE = 1.69$) resulted in a BF of 0.58 (using a half normal with $SD = 6.5$), suggesting that the design was insensitive.

Analyses on error rates.   The same ANOVA analysis was also performed on mean error percentages (see Figure 3). The main effect of Congruency$_n$ was significant, $F(2, 56) = 37.89$, $p < .001$. The motor congruency effect was significant, $t(28) = 5.98$, $p < .001$; RespConflict$_n$ − StimConflict$_n$ $= 10.4\%$, the perceptual congruency effect was also significant but extremely weak, $t(28) = 3.65$, $p = .0011$; StimConflict$_n$ − Identical$_n$ $= 0.4\%$. As in Experiment 1, errors were almost nonexistent for both Identical and StimConflict trials (0.05% and 0.45%, respectively), whereas error rates were high for RespConflict trials (10.9%). The main effect of Congruency$_{n−1}$ was also significant, $F(2, 56) = 16.31$, $p < .001$, indicating that participants made fewer errors on the current trial following a conflict on $n − 1$ (Identical$_{n−1}$ $= 4.5\%$, StimConflict$_{n−1}$ $= 3.8\%$, and RespConflict$_{n−1}$ $= 2.7\%$). Follow-up analyses showed a significant difference both between Identical$_{n−1}$ and StimConflict$_{n−1}$, $t(28) = 2.52$, $p = .018$, and between StimConflict$_{n−1}$ and RespConflict$_{n−1}$, $t(28) = 5.45$, $p < .001$.

The 2-way interaction between Congruency$_n$ and Congruency$_{n−1}$ was significant, $F(4, 112) = 18.99$, $p < .001$, indicating the presence of conflict adaptation. We then examined the specific cause and impact of conflict adaptation. The overall conflict on $n − 1$ modulated significantly the overall congruency effect; $t(28) = 5.62$, $p < .001$; adaptation $= 5.9\%$. The motor conflict on $n − 1$ significantly impacted the motor congruency effect, $t(28) = 3.80$, $p < .001$; adaptation $= 4\%$, but it did not impact the perceptual congruency effect, $t(28) = −1.52$, $p = .139$. Finally, the perceptual conflict on $n − 1$ significantly modulated the motor congruency effect, $t(28) = 2.84$, $p = .008$; adaptation $= 2.2\%$, whereas it did not impact the perceptual congruency effect, $t(50) = −0.02$, $p = .986$.

Discussion

Analyses on RTs indicated perceptual and motor congruency effects on the current trial. Similar to Experiment 1, adaptive control triggered by a motor conflict selectively affected the motor congruency effect. In contrast to the previous experiment, we also found that adaptive control triggered by a perceptual conflict selectively affected the perceptual congruency effect. Important to note, the perceptual congruency effect in this experiment was significantly stronger than in the conscious condition of Experi-

ment 1 (55 ms vs. 36 ms; $F(1, 78) = 10.98$, $p = .001$), whereas the motor effect was significantly weaker than in Experiment 1 (45 vs. 68 ms; $F(1, 78) = 9.12$, $p = .003$). An additional analysis directly comparing the size of the congruency effects across both experiments indeed showed a significant interaction between Congruency$_n$ (three levels) and Experiments (two levels), $F(2, 156) = 6.11$, $p = .003$. The perceptual dissimilarity between the prime and target might have caused more interference in this experiment due to the absence of a metacontrast mask. In turn, this higher perceptual conflict in the previous trial might have increased the need for reducing it in the current trial, possibly through a mechanism of attentional amplification to target task-relevant features (Egner & Hirsch, 2005).

We found it noteworthy that the RespConflict 180° condition was removed in Experiment 2. As a consequence, the position of the primes can inform about the direction of the targets in this experiment. The prime reduced the number of possible target directions from four to three. This other difference between Experiments 1 and 2 could also explain the difference in the size of perceptual and motor congruency effects.

Analyses on errors exactly replicate the error results of Experiment 1. Adaptive control on the motor congruency effect was triggered by both perceptual and motor conflicts.

Experiment 3

The design of Experiment 2 (in which we removed RespConflict 180°) makes it possible to dissociate the pure motor effect from the pure perceptual effect during conflict adaptation. However, only the conscious condition was tested. In Experiment 3, the same design was used but extended to the unconscious condition. Moreover, this new experiment was designed to study the role of two temporal factors that were confounded in Experiment 1. Indeed, visibility of the prime (i.e., the level of consciousness) was manipulated by changing prime duration and prime–target stimulus-onset asynchrony (SOA) in Experiment 1. Previous studies have shown that these latter two variables also have an impact on the size of the priming effects (see, e.g., Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), and more recent studies have suggested controlling these variables in conflict adaptation designs (e.g., Ansorge et al., 2011; Desender et al., 2013). Therefore, Experiment 3 was carried out to compare conflict adaptation between different SOA and different prime duration conditions. Note that using arrow primes masked by metacontrast masks (or random-line masks) in combination with long mask–target SOAs (i.e., 100–150 ms) induces negative compatibility effects instead of positive compatibility effects (see, e.g., Atas, San Anton, & Cleeremans, 2014; Eimer & Schlaghecken, 2003; Lingnau & Vorberg, 2005; McBride, Boy, Husain, & Sumner, 2012). Therefore, we used random pixel masks, which have elicited positive compatibility effects even at a mask–target SOA of 100 ms in previous studies (Desender, Van Opstal, & Van den Bussche, 2014; Reuss, Desender, Kiesel, & Kunde, 2014; Verleger, Jaśkowski, Aydemir, van der Lubbe, & Groen, 2004).

Method

Forty-nine students (38 women; mean age $= 22.5$) from the Université Libre de Bruxelles participated in return for a compen-

sation of 9 euro. Participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment. All apparatus, stimuli, design, and procedure were the same as in Experiment 2, except the following modifications. Stimuli were black (<1 cd/m^2) and displayed at the center of the screen on a white background (48 cd/m^2) at an 800×600 resolution and a refresh rate of 85 Hz. The tilted double arrow was used as prime and target (visual angle of approximately $2° \times 0.9°$). Four different masks consisting of randomly selected white (48 cd/m^2), gray (17 cd/m^2), and black (<1 cd/m^2) pixels were used (3.9° wide and 2.7° high). In each trial containing masks, three of these masks were randomly selected, and presented in a random order. The prime and the mask stimuli appeared at the center of the screen, whereas the target was presented in duplicate, either just above and below the mask, or just to the left and to the right of the mask. The vertical and horizontal presentations of the two targets relative to the mask were randomly selected across trials. The distance from the center of the screen to the center of the vertical and horizontal target arrows subtended a visual angle of 2.6° and 3.1°, respectively; see Figure 4.

Four Mask-Time conditions were used (see Figure 4). The target was always presented for 129 ms. For the three conditions with a long prime–target SOA, the delay between the onset of the prime and the onset of the target was 117.5 ms. For the condition with a short prime–target SOA, this delay was 47 ms. In the condition "unmasked, long prime duration, and long prime–target SOA," called ULL, the prime was presented for 94 ms, followed by a blank of 23.5 ms, which was followed by the target. In the condition "unmasked, short prime duration, and long prime–target SOA," called USL, the prime was presented for 23.5 ms, followed by a blank of 94 ms, which was followed by the target. In the condition "masked, short prime duration, and long prime–target SOA," called MSL, the prime was presented for 23.5 ms, followed by three masks of 23.5 ms each, followed by a blank of 23.5 ms, which was followed by the target. The condition "masked, short prime duration, and short prime–target SOA," called MSS, was the same as MSL, except that the target appeared alongside the second mask. In brief, comparing ULL and USL allowed us to isolate the effect of prime duration. Comparing USL and MSL allowed us to extract the effect of masking when prime duration was constant. Finally, comparing MSL and MSS allowed us to examine the effect of prime–target SOA when masking was constant. Each Mask-Time condition was blocked. Twelve blocks of the priming task (96 trials each) were followed by four blocks of the visibility task (48 trials each). Half of the participants performed the priming blocks in the following order: four ULL, four USL, four MSL, and four MSS blocks. The visibility blocks (performed after the priming blocks) had the same ordering of the Mask-Time conditions. The other half of the participants received the reverse order.

Results

Exclusion of trials. Identical repetitions of prime and target between trials $n - 1$ and n (5.5%)[3], trials following an error (4.5%), the first trial of each block (1.04%), and RTs <100 or >1000 (0.18%) were excluded from the analyses of both RTs and error rates. For the RT analyses, errors were also excluded (5%).

Analyses on RTs. Mean RTs from correct responses were submitted to a repeated measures ANOVA analysis with Congruency$_n$ (Identical, StimConflict, and RespConflict), Congruency$_{n-1}$ (Identical, StimConflic,t and RespConflict), and Mask-Time (ULL, USL, MSL, and MSS) as within-subject factors. Results of this analysis are presented in Figure 5. The main effect of Congruency$_n$ was significant, $F(2, 96) = 416.48$, $p < .001$. The main effect of Congruency$_{n-1}$ was also significant, $F(2, 96) = 27.53$, $p < .001$, indicating that participants were slower on the current trial following a conflict on $n - 1$ (Identical$_{n-1}$ = 377 ms, StimConflict$_{n-1}$ = 378 ms, and RespConflict$_{n-1}$ = 383 ms). The main effect of Mask-Time was also significant, $F(3, 144) = 50.17$, $p < .001$; ULL = 394, USL = 391, MSL = 361, and MSS = 371). The two-way interaction between Congruency$_n$ and Mask-Time was also significant, $F(6, 288) = 124.25$, $p < .001$, indicating larger congruency effects with unmasked compared with masked primes (see Table 1). Perceptual and motor congruency effects were significant for each level of Mask-Time (see Table 1).

The two-way interaction between Congruency$_n$ and Congruency$_{n-1}$, $F(4, 192) = 3.35$, $p = .011$, and the three-way interaction between Congruency$_n$ and Congruency$_{n-1}$ and Mask-Time, $F(12, 576) = 2.71$, $p = .001$ were both significant.

The specific cause and impact of conflict adaptation were subsequently examined for each Mask-Time condition. For the ULL condition, the motor conflict on $n - 1$ (StimConflict$_{n-1}$ vs. RespConflict$_{n-1}$) significantly impacted the motor congruency effect (RespConflict$_n$ − StimConflict$_n$); $t(48) = 2.42$, $p = .019$; adaptation = 11 ms. For the USL condition, the overall conflict on $n - 1$ (Identical$_{n-1}$ vs. RespConflict$_{n-1}$) significantly modulated the overall congruency effect (RespConflict$_n$ − Identical$_n$); $t(48) = 4.75$, $p < .001$; adaptation = 19 ms. For this condition, the motor conflict on $n - 1$ also significantly impacted the motor congruency effect; $t(48) = 2.78$, $p = .008$; adaptation = 10 ms. All other conflict-adaptation effects were not significant ($ps > .10$). Using the same approach as in Experiment 1, using the USL data to compute expected magnitudes, a Bayes factor of 0.76 for conflict adaptation in the MSL condition, and 0.15 for the MSS condition suggested that there was indeed no evidence for unconscious conflict adaptation in our data.

These results are thus very similar to those of Experiment 1: adaptive control triggered by a motor conflict selectively affected the motor congruency effect. This was observed only for unmasked conditions. The results also suggest that there is no effect of prime duration on conflict adaptation (or on priming) between the two unmasked conditions, and that there is no effect of prime–target SOA on conflict adaptation (or on priming) between the two masked conditions.

Analyses on error rates. The same ANOVA analysis was performed on mean error percentages (see Figure 5). The main effect of Congruency$_n$ was significant, $F(2, 96) = 77.29$, $p < .001$. The main effect of Congruency$_{n-1}$ was also significant, $F(2, 96) = 3.10$, $p = .05$, indicating that participants made fewer errors on the current trial following a conflict on $n - 1$ (Identical$_{n-1}$ = 5.5%,

---

[3] In this experiment, trials from the list of 24 different prime–target couples (i.e., four Identical, four StimConflict 90°, and four RespConflict 90° trials; horizontal and vertical disposition of the target) were presented randomly until the end of the list. This was done four times successively. This list led to 5.5% of identical repetitions.
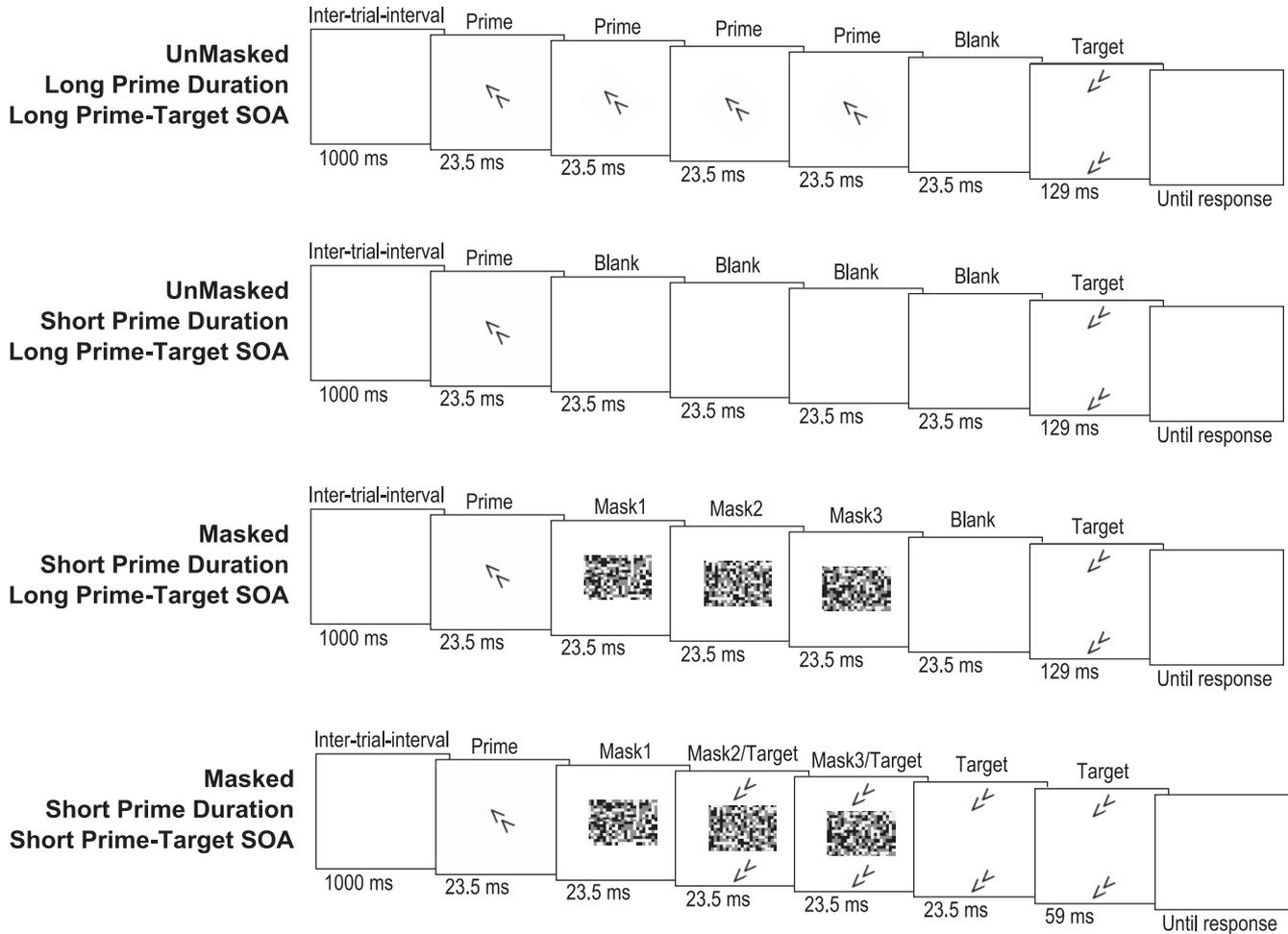
Figure 4. Trial procedure of the priming task for the four Mask–Time conditions (ULL, USL, MSL, and MSS) in Experiment 3.

$StimConflict_{n-1} = 5.1\%$, and $RespConflict_{n-1} = 4.8\%$). Furthermore, the main effect of Mask-Time was significant, $F(3, 144) = 16.92$, $p < .001$: Participants made more errors to unmasked primes (ULL = 6.9%, USL = 5.8%) than to masked primes (MSL = 3.7%, MSS = 4.2%). The two-way interaction between $Congruency_n$ and Mask-Time was also significant, $F(6, 288) = 37.42$, $p < .001$, see Table 1 for follow-up results. The two-way interaction between $Congruency_n$ and $Congruency_{n-1}$ was significant, $F(4, 192) = 18.99$, $p = .006$, indicating the presence of conflict adaptation. The three-way interaction was not significant, $F(12, 576) = 1.12$, $p = .337$, indicating no modulation of conflict adaptation by Mask-Time. For the two-way interaction, we then examined the specific cause and impact of conflict adaptation. The overall conflict on $n - 1$ modulated significantly the overall congruency effect; $t(48) = 3.10$, $p = .003$; adaptation = 2%. The perceptual conflict on $n - 1$ tended to modulate the motor congruency effect, as indicated by a marginal effect, $t(48) = 1.99$, $p = .053$; adaptation = 1.3%. Conflict adaptation on errors seems not to have differed between the different Mask-Time conditions. Note that when examining conflict adaptation in each condition, only the ULL condition showed a significant conflict-adaptation effect on errors (the

overall conflict on $n - 1$ modulating the overall congruency effect: $t(48) = 2.45$, $p = .018$, adaptation = 4.4%, all other $ps > .113$).

Prime visibility. For the MSS condition, participants performed the prime discrimination task at chance level (mean accuracy = 52%, mean $d' = 0.12$). For all other conditions, results clearly show an above chance performance, see Table 2. In contrast to the priming task, results indicate a significant effect of prime–target SOA on prime discrimination performance. There was also an effect of masking on prime discrimination performance.

Discussion

To sum up, removing the mask while keeping temporal factors constant (i.e., the prime duration short and the prime–target SOA long) increased congruency effects and prime consciousness, and elicited significant conflict adaptation (see USL–MSL). In contrast, increasing prime–target SOA while keeping prime duration and masking constant did not increase congruency effects and conflict adaptation, but slightly increased prime visibility/consciousness (see MSL–MSS). Finally, increasing prime duration had no additional effect on behavior when the prime was
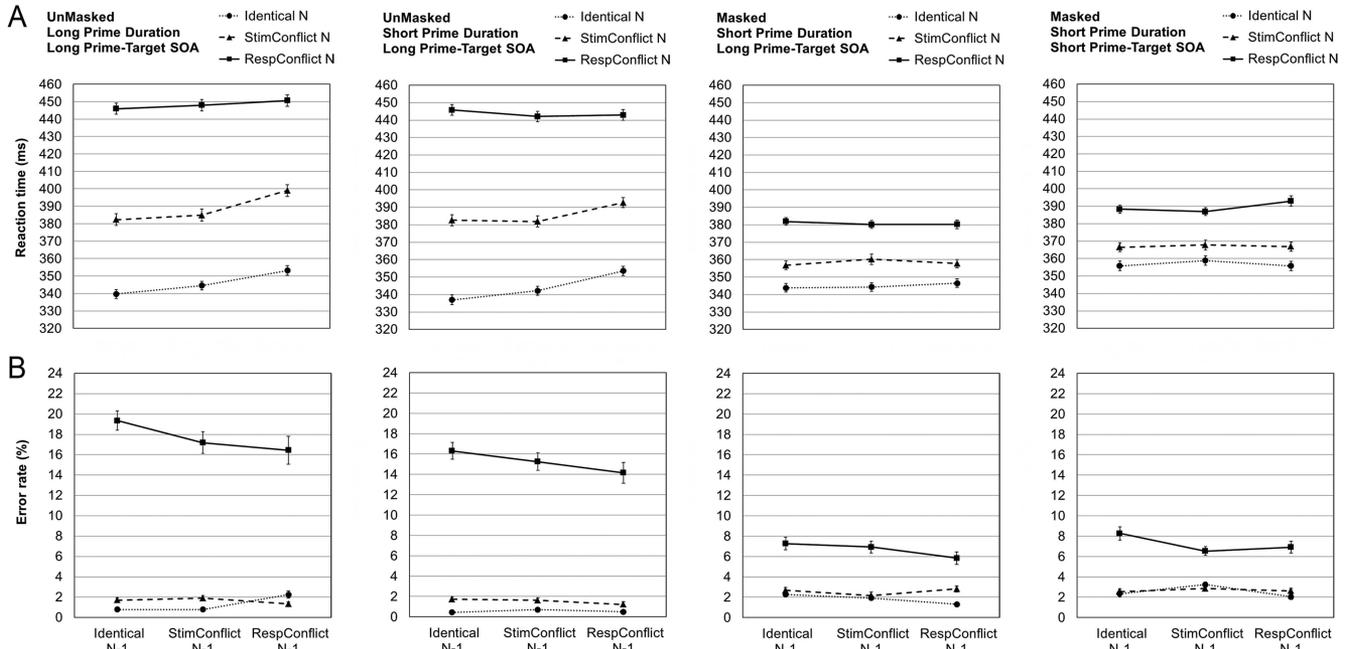
Figure 5. Results of Experiment 3: (A) mean RTs in ms and (B) mean error percentage as function of Congruency (Identical, StimConflict, and RespConflict), and Mask Time (ULL, USL, MSL, and MSS). Error bars represent one standard error of the mean.

already unmasked and the prime–target SOA was already long (see ULL–USL).

It should be noted that in all the studies about (un)conscious conflict adaptation (and priming), consciousness of the participant (i.e., the visibility performance) was not manipulated directly. Only stimulus signal (e.g., masking, prime duration, stimulus contrast, etc.) was manipulated directly. Therefore, one should be careful when

making conclusions about the role of consciousness in conflict adaptation. If we found simultaneously significant conflict adaptation and above chance visibility performance as stimulus signal increased, what can we conclude from this? Although it would be appealing to conclude that consciousness is what is causing the conflict adaptation, this statement is not fully correct because consciousness is not what was manipulated here. Instead, we can only conclude that the strength

Table 1

Perceptual and Motor Congruency Effects on RTs and on Errors for Each Mask–Time Condition and Between Mask–Time Conditions

	Perceptual congruency effects						Motor congruency effects					
	on RTs (ms)			on errors (%)			on RTs (ms)			on errors (%)		
Conditions/Comparisons												
Conditions	t	p	Effect	t	p	Effect	t	p	Effect	t	p	Effect
ULL	13.78	.000	43***	1.89	.065	.4	13.17	.000	59***	8.47	.000	15.9***
USL	14.78	.000	41***	2.50	.016	1.0*	15.83	.000	58***	9.57	.000	13.9***
MSL	8.52	.000	13***	1.97	.055	.8	7.27	.000	23***	5.11	.000	4.2***
MSS	6.49	.000	10***	.18	.858	.1	9.37	.000	22***	5.92	.000	4.7***
	Comparisons of perceptual effects between conditions						Comparisons of motor effects between conditions					
	on RTs (ms)			on errors (%)			on RTs (ms)			on errors (%)		
Comparisons	t	p	Diff.	t	p	Diff.	t	p	Diff.	t	p	Diff.
ULL-USL[a]	.54	.595	1	−1.57	.123	−.6	.04	.968	0	1.47	.147	2.0
USL-MSL[b]	10.36	.000	28***	.37	.714	.2	11.32	.000	36***	8.37	.000	9.7***
MSL-MSS[c]	1.47	.149	3	1.32	.195	.7	.198	.844	1	−.77	.445	−.4

Note. Diff. = Difference; RT = reaction time; ULL = unmasked, long prime duration, and long prime–target stimulus-onset asynchrony (SOA); USL = unmasked, short prime duration, and long prime–target SOA; MSL = masked, short prime duration, and long prime–target SOA; MSS = masked, short prime duration, and short prime–target SOA.
[a] Comparison ULL-USL to examine the impact of prime duration. [b] Comparison USL-MSL to examine the impact of masking. [c] Comparison MSL-MSS to examine the impact of prime-target SOA.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2

Prime Discrimination Performance (Accuracy and d′) for Each Mask–Time Condition and Between Mask–Time Conditions

Conditions/ Comparisons	Accuracy (%)			d′		
Conditions	t	p	Effect	t	p	Effect
ULL	9.31	.000	78***	8.68	.000	1.90***
USL	9.88	.000	78***	9.13	.000	1.90***
MSL	4.54	.000	59***	4.41	.000	.49***
MSS	1.99	.052	52	2.15	.037	.12*
	Comparisons between conditions					
	Accuracy (%)			d′		
Comparisons	t	p	Diff.	t	p	Diff.
ULL-USL[a]	−.12	.907	0	.00	.998	0
USL-MSL[b]	7.45	.000	19***	7.88	.000	1.41***
MSL-MSS[c]	3.63	.001	7***	3.44	.001	.37***

Note. Diff. = Difference; ULL = unmasked, long prime duration, and long prime–target stimulus-onset asynchrony (SOA); USL = unmasked, short prime duration, and long prime–target SOA; MSL = masked, short prime duration, and long prime–target SOA; MSS = masked, short prime duration, and short prime–target SOA.
[a] Comparison ULL-USL to examine the impact of prime duration. [b] Comparison USL-MSL to examine the impact of masking. [c] Comparison MSL-MSS to examine the impact of prime–target SOA.
* $p < .05$. ** $p < .01$. *** $p < .001$.

of the stimulus signal (i.e., unmasking) is what caused both conscious access and conflict adaptation.

Finally, in the masked-long SOA condition, it might be intriguing that discrimination above chance was observed in the visibility test, but no conflict adaptation occurred. Of note, the average visibility performance was only 59% when conflict adaptation was not observed (masked conditions) and 78% when conflict adaptation was observed (unmasked conditions). This result might be indicative that a minimal conscious access is not sufficient to observe conflict adaptation, but instead a richer level of consciousness might be needed. Or said more accurately, greater stimulus strength might be needed to observe conflict adaptation above chance than to observe visibility above chance. Another possible explanation is that visibility tasks typically overestimate prime visibility because participants direct their attention to the primes in the task, whereas they do not during the main task, from which the conflict adaptation is assessed (Vermeiren & Cleeremans, 2012).

General Discussion

In conflict tasks, conflict detection between relevant and irrelevant information on the previous trial typically leads to smaller conflict effects on the current trial (Gratton et al., 1992). This so-called conflict-adaptation effect has been interpreted as an expression of cognitive control: Following the detection of competing demands, participants are thought to increase their level of control, resulting in better shielding against interfering information (Botvinick et al., 2001). A central issue within this framework is what type of conflict is likely to trigger a modulation of cognitive control, and what type of conflict is accordingly reduced.

In this study, we examined the locus of conflict adaptation both in terms of level of processing (perceptual vs. motor) and in terms

of level of consciousness (unconscious vs. conscious). To examine the role of processing level, we mapped four arrow stimuli (i.e., up-left, down-left, up-right, and down-right arrows) onto two responses (i.e., left and right; see Figure 1B) in a prime–target paradigm. This resulted in three trial types: Identical trials (e.g., up-left–up-left) inducing no conflict, StimConflict trials (e.g., up-left–down-left) inducing a perceptual conflict, and RespConflict trials (e.g., up-left–up-right) inducing both perceptual and motor conflict. Comparing the first two trial categories allowed us to isolate perceptual conflict, whereas comparing the last two trial categories allowed us to isolate motor conflict. To examine the role of the level of consciousness, prime duration was manipulated in Experiment 1 in the same way as Kunde (2003) and Van Gaal et al. (2010). The primes were masked by a metacontrast mask and presented for either a short duration (i.e., 14 ms), leading to unconscious conflict, or a long duration (i.e., 128 ms), leading to conscious conflict. In Experiment 3, a better manipulation of the level of consciousness was carried out by separately manipulating prime duration, masking, and prime–target SOA. Thus, when one of the three variables was manipulated (e.g., masking: mask vs. no mask), the two other variables were kept constant (e.g., the prime duration was kept short, and the prime–target SOA was kept long between the masked and unmasked conditions).

Analyses on RTs in Experiments 1 and 3 revealed that adaptive control was only triggered by a motor conflict on the previous trial, and it selectively affected motor congruency effects. Moreover, this conflict-adaptation effect was only triggered by a conscious conflict: When primes in the previous trial were unconscious, no adaptation effects were observed in the current trial. However, when primes in the previous trial were consciously perceived, adaptation occurred regardless of the level of consciousness in the current trial. Taken together, these results demonstrate that adaptive control triggered by a conscious motor conflict selectively affects motor congruency effects (both conscious and unconscious) on the current trial. In Experiment 2, the same stimuli and temporal procedure were used as in the conscious condition of Experiment 1, but the prime was not masked. This second experiment replicated the previous finding: The detection of a motor conflict on the previous trial selectively led to a reduction of the motor congruency effect on the current trial. In addition, Experiment 2 indicated that perceptual conflict on the previous trial selectively reduced the perceptual congruency effect on the current trial. Important to note, the perceptual congruency effect in Experiment 2 was significantly greater than in the conscious condition of Experiment 1 (only differing by masking)[4]. This suggests that the absence of a metacontrast mask in Experiment 2 increased the perceptual interference of the prime on target processing, so that more top-down attention might have been allocated on target stimulus features to reduce this greater conflict (Egner & Hirsch, 2005).

To our knowledge, only a few studies so far have examined the locus of conflict adaptation in terms of level of processing within the same task. In Verbruggen, Notebaert, Liefooghe, and Vandierendonck (2006), the task involved a six-stimulus/three-response

---

[4] Note also that the perceptual congruency effect was greater in Experiment 2 than in the two unmasked conditions of Experiment 3 (55 vs. 43 and 41).

mapping and participants were instructed to respond to the color of a middle line while ignoring the color of two flanking lines. The authors observed that perceptual conflict on the previous trial selectively reduced the perceptual congruency effect on the current trial (i.e., the interaction was significant). Noteworthy in that study is that the main congruency effect on the current trial (i.e., regardless of the conflict on the previous trial) was only motor but not perceptual, which renders the interpretation of this perceptual adaptation effect difficult. Moreover, Liu, Chen, Li, Li, and West (2012) suggested that the unbalanced frequencies of target colors in each condition (i.e., Previous × Current Congruency) of this study might have accounted for its results, because differences in processing speed were observed between two colors mapped onto the same response. Therefore, Liu et al. (2012) used the same color-based flanker task but controlled for the frequency of target colors in each condition. They observed that the motor congruency effect but not the perceptual congruency effect was reduced by conflict on the previous trial. Although this study suggests pure motor adaptation after conflict, we found adaptation of both the perceptual and motor congruency effects in the present study. However, when a metacontrast mask was displayed after the prime, the perceptual congruency effect was smaller and perceptual adaptation was nonexistent. This suggests that perceptual conflict needs to be sufficiently high to induce adaptive behavior. Our results are consistent with the model of Botvinick and colleagues (2001) and Shenhav et al. (2013), both of which predict that the degree of top-down control on the current trial directly depends on the degree of conflict detected during the previous trial. Selective adaptation of perceptual congruency effects was also demonstrated in the neuroimaging study of Egner and Hirsch (2005). Using a face–word Stroop task, these authors found that the fusiform face area (FFA; i.e., the visual area specialized in face processing) was more activated during incongruent trials following incongruent trials than incongruent trials following congruent trials. This modulation of the FFA was only observed when faces were task-relevant, and was mediated by dorsolateral prefrontal cortex, an area involved in implementing top-down control (e.g., MacDonald, Cohen, Stenger, & Carter, 2000). These results thus suggest that conflict detection might trigger an increase of top-down selective attention toward perceptual features of the target.

Our RT results are consistent with the view that conflict-driven control is domain-specific (Egner, 2008): The detection of a specific type of conflict (i.e., either perceptual or motor) triggers a mode of control specifically involved in reducing that particular conflict. This hypothesis is consistent with the idea that ACC has a critical role both in detecting conflict and in specifying the identity and intensity of cognitive control adjustment (Shenhav et al., 2013). That is, a central system both detects the occurrence of a specific conflict and communicates the required adjustments to other brain areas. Thus, the detection of a perceptual conflict on the previous trial might have specifically increased the need for orienting attention toward task-relevant stimulus features, reducing only the perceptual conflict in the actual trial. Similarly, the detection of a motor conflict on the previous trial might have specifically increased the need for selecting the relevant response/inhibiting the irrelevant motor activation, reducing only the motor conflict in the current trial.

Previous studies investigating whether conflict-driven control was domain-general or domain-specific have always combined two different types of tasks in the same paradigm. For instance, Egner et al. (2007) used a *factorial* task-crossing design that combined a Stroop task (in which conflict is stimulus-based; color words printed in congruent or incongruent inks) with a Simon task (in which conflict is response-based; a particular stimulus at left or right of fixation requiring a left-hand response). The authors also found evidence for a domain-specific conflict-control mechanism: Stroop conflict on the previous trial reduced the Stroop conflict in the actual trial, but did not modulate the Simon conflict, and vice versa (e.g., Wendt, Kluwe, & Peters, 2006). Contrasting this observation, studies that have combined different tasks in a *nonfactorial* task-crossing design have found contradictory results. Some have observed evidence for domain-general conflict adaptation (Freitas, Bahar, Yang, & Banai, 2007; Kan et al., 2013; Kleiman, Hassin, & Trope, 2014; Stürmer, Seiss, & Leuthold, 2005); others have found evidence for domain specificity of conflict-driven control (Kiesel, Kunde, & Hoffmann, 2006). As Egner (2008) pointed out, generalization of conflict adaptation between tasks in nonfactorial task-crossing designs might be due to task-switching effects rather than to conflict-adaptation effects. Moreover, whereas the Simon task induces a pure motor conflict (Stürmer et al., 2002), all other tasks—that is, the Stroop task, the flanker task or the prime–target task—are able to induce both perceptual and motor conflict (Kouider & Dehaene, 2009; Nigbur et al., 2012; van Veen et al., 2001; Wendt et al., 2007). It is thus not surprising that conflict overlapping between tasks might sometimes occur (Kunde & Wuhr, 2006), rendering any conclusions about domain-specificity of conflict-triggered control in such paradigms problematic. Our RT analysis provided evidence that domain specificity of conflict-adaptation processes can also be found within the same task. Supporting this finding, Soutschek, Taylor, Muller, and Schubert (2013) recently showed that TMS administered to the presupplementary motor area (i.e., an area involved in response selection) increased the motor congruency effect, but did not modulate the perceptual congruency effect. In contrast, transcranial magnetic stimulation administered to the posterior intraparietal sulcus/inferior parietal lobule (i.e., involved in top-down selective attention) selectively increased the perceptual congruency effect.

Although adaptive control seems to be specific for perceptual and motor conflict for RTs, it might be more general for error rates. Indeed, we observed that adaptation of the motor congruency effect was driven by both perceptual and motor conflict on errors. This pattern of results was robust, as it was found in all three experiments.

We find it noteworthy that perceptual conflict and motor conflict simultaneously differed regarding task relevance in the present study. The leftward–rightward orientation (used to isolate motor conflict) was task-relevant, whereas the upward–downward orientation (used to isolate perceptual conflict) was irrelevant for task performance. However, the upward–downward orientation is an intrinsic feature of the arrow head. As such, it should be processed and able to influence target performance even if its processing is not directly required by the task instructions. The results we found were consistent with this prediction. A perceptual congruency effect was systematically observed, demonstrating that the upward and downward orientations were processed. Furthermore, perceptual conflict adaptation was observed on RT in Experiment 2 and on errors in both Experiments 1 and 2. In other

words, the applied method was sufficiently sensitive to induce perceptual congruency. Nevertheless, as task relevance of conflict is an important factor for conflict adaptation (Hazeltine, Lightman, Schwarb, & Schumacher, 2011), further research is needed that directly manipulates task relevance for perceptual conflict (for a relevant methodology, see Ansorge et al., 2011).

Concerning the locus of conflict adaptation in terms of level of consciousness, we did not observe unconsciously triggered conflict adaptation on RTs either in Experiment 1 or 3. Note that Experiment 1 had the same experimental design as in van Gaal et al. (2010), in which an unconsciously triggered conflict adaptation was found on both RTs and errors. In contrast to RT results, Experiment 1 did show that an unconscious conflict triggered adaptation on errors, although this adaptation effect was small in magnitude and restricted to the overall conflict. Consistent with our Experiment 1, Francken et al. (2011), using arrow stimuli in a similar paradigm to van Gaal et al. (2010), also observed unconsciously triggered adaptation only on error rates. Note that Experiment 3 did not show evidence for an unconscious conflict adaptation even on errors.

Why do we and others systematically observe conflict adaptation when the conflict is experienced consciously, but observe a rather unsystematic pattern when the conflict is processed unconsciously? One possible explanatory factor may be the magnitude of the unconscious conflict. Indeed, it is systematically observed that the magnitude of unconscious compatibility effects (on both RTs and errors) are smaller than the magnitude of conscious compatibility effects (but see Francken et al., 2011, for an exception). The ACC is thought to be the brain area that detects conflict and inform other brain areas to implement cognitive control adjustments. According to Shenhav et al.'s (2013) model, there might be a minimal threshold on the amount of conflict needed to trigger ACC activation. Therefore, the interference caused by unconscious irrelevant stimuli might not always be sufficiently strong or aversive to be used as information indicating that additional control is needed to maintain an adequate level of performance and maximize the attainment of reward. It might also be that unconscious conflict adaptation is sensitive to the stimulus design and to the size of stimulus set. Indeed, the two experiments showing clear unconsciously triggered conflict adaptation only used two arrows or two digits (Desender et al., 2013; van Gaal et al., 2010). A final possibility is that in unconscious priming, conflict adaptation only occurs when participants become aware of the response conflict on a metacognitive level. Indeed, a recent study only observed conflict adaptation after trials on which participants' conflict experience was in agreement with the actual congruency (Desender et al., 2014). Future studies might be usefully directed to address how perceptual and motor conflict (adaptation) relate to subjective conflict awareness.

As highlighted previously, robust and consistent differences in the performance of the participants were observed between error rates and RTs. Indeed, across all the experiments, error rates seemed to favor domain-general processing, whereas RTs seemed to favor domain-specific processing. Furthermore, although error rates pointed toward the possibility of unconscious adaptation, this did not seem to be the case for the RTs. The exact reason for these different patterns remains an open issue, but some possible explanations can be provided. One interpretation is that, in our study, error rates were a more sensitive measure of cognitive adaptation.

Indeed, even though the instructions stressed both speed and accuracy, the nature of our task (i.e., rapid series of flashes, extreme ease of task, etc.) may have caused participants to respond in favor speed over accuracy. This interpretation might explain why error rates provided evidence for domain-general and unconscious adaptation, and RTs did not. On the other hand, such an interpretation in terms of differences in sensitivity is insufficient in explaining why RTs indicated differentiation between all levels of processing (i.e., RTs Identical < StimConflict < RespConflict) and error rates did not (i.e., Identical = StimConflict < RespConflict). Indeed, errors were committed only when the prime activated the response hand opposite the target (i.e., in RespConflict trials), and were virtually nonexistent when the prime activated the same response as the target (i.e., in both Identical and StimConflict trials).

Another possible interpretation, which is not necessarily mutually exclusive of the previous interpretation of the observed dissociation, is that error rates and RTs are sensitive to different aspects of the same underlying processing mechanisms. As indicated above, errors seem to have been influenced only by motor processes and not by stimulus conflict in the current study (Ridderinkhof, 2002; van den Wildenberg et al., 2010), whereas RTs seem sensitive to both. Another important difference between both measures concerns the temporal dynamics of processing. Erroneous responses are typically the fastest responses and are thought to reflect stronger initial action impulsivity (Ridderinkhof, 2002; Stins, Polderman, Boomsma, & de Geus, 2007; van den Wildenberg et al., 2010). In contrast, RTs used to measure conflict processing are based only on correct responses and are thus cleaned from these fastest motor impulses. Given that RTs and error rates can tap on different aspects of the same underlying ongoing processing, it might not be that surprising to observe different patterns of results for both measures.

On a final note, a limitation of the current study is that it is unclear to what extent other sources, apart from cognitive control, added to the observed effect. Some authors have argued that the Gratton effect results from processes unrelated to cognitive control, such as specific features that repeat between trials (e.g., Hommel, Proctor, & Vu, 2004; Mayr et al., 2003) or contingency confounds in the design (Schmidt & De Houwer, 2011). However, recently a number of studies provided evidence that the effect can still be observed, even when all possible known confounds are controlled for (see, e.g., Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014; Notebaert & Verguts, 2007; Ullsperger, Bylsma, & Botvinick, 2005). Hence, although other sources apart from conflict adaptation might have potentially added to the current results, there is substantial evidence suggesting that this is certainly not the whole story. Nonetheless, future researchers might want to use more advanced paradigms to examine whether our results hold, once controlled for all known confounds.

Conclusion

To conclude, our results on RTs indicated that a specific type of conscious conflict (i.e., either perceptual or motor) triggered behavioral adjustments that selectively impacted on that particular type of conflict. In contrast, results on errors showed that the detection of any type of conflict in a previous trial—perceptual,

motor, conscious, and sometimes even unconscious—reduced the number of errors on response-conflict trials.

References

Ansorge, U., Fuchs, I., Khalid, S., & Kunde, W. (2011). No conflict control in the absence of awareness. *Psychological Research, 75,* 351–365. http://dx.doi.org/10.1007/s00426-010-0313-4

Atas, A., San Anton, E., & Cleeremans, A. (2014). The reversal of perceptual and motor compatibility effects differs qualitatively between metacontrast and random-line masks. *Psychological Research, 79,* 813–828.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624–652. http://dx.doi.org/10.1037/0033-295X.108.3.624

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97,* 332–361. http://dx.doi.org/10.1037/0033-295X.97.3.332

Dehaene, S., & Changeux, J. P. (2011). Experimental and theoretical approaches to conscious processing. *Neuron, 70,* 200–227. http://dx.doi.org/10.1016/j.neuron.2011.03.018

Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J. B., Le Bihan, D., & Cohen, L. (2004). Letter binding and invariant recognition of masked words: Behavioral and neuroimaging evidence. *Psychological Science, 15,* 307–313. http://dx.doi.org/10.1111/j.0956-7976.2004.00674.x

Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J. F., Poline, J. B., & Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience, 4,* 752–758. http://dx.doi.org/10.1038/89551

Desender, K., Van Lierde, E., & Van den Bussche, E. (2013). Comparing conscious and unconscious conflict adaptation. *PLoS ONE, 8,* e55976. http://dx.doi.org/10.1371/journal.pone.0055976

Desender, K., Van Opstal, F., & Van den Bussche, E. (2014). Feeling the conflict: The crucial role of conflict experience in adaptation. *Psychological Science, 25,* 675–683. http://dx.doi.org/10.1177/0956797613511468

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18,* 193–222. http://dx.doi.org/10.1146/annurev.ne.18.030195.001205

Dienes, Z. (2011). Bayesian versus orthodox statistics: Which side are you on? *Perspectives on Psychological Science, 6,* 274–290. http://dx.doi.org/10.1177/1745691611406920

Duthoo, W., Abrahamse, E. L., Braem, S., Boehler, C. N., & Notebaert, W. (2014). The congruency sequence effect 3.0: A critical test of conflict adaptation. *PLoS ONE, 9,* e110462. http://dx.doi.org/10.1371/journal.pone.0110462

Egner, T. (2008). Multiple conflict-driven control mechanisms in the human brain. *Trends in Cognitive Sciences, 12,* 374–380. http://dx.doi.org/10.1016/j.tics.2008.07.001

Egner, T., Delano, M., & Hirsch, J. (2007). Separate conflict-specific cognitive control mechanisms in the human brain. *NeuroImage, 35,* 940–948. http://dx.doi.org/10.1016/j.neuroimage.2006.11.061

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8,* 1784–1790. http://dx.doi.org/10.1038/nn1594

Eimer, M., & Schlaghecken, F. (2003). Response facilitation and inhibition in subliminal priming. *Biological Psychology, 64,* 7–26. http://dx.doi.org/10.1016/S0301-0511(03)00100-5

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters on the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149. http://dx.doi.org/10.3758/BF03203267

Francken, J. C., Gaal, S., & de Lange, F. P. (2011). Immediate and long-term priming effects are independent of prime awareness. *Consciousness and Cognition, 20,* 1793–1800. http://dx.doi.org/10.1016/j.concog.2011.04.005

Freitas, A. L., Bahar, M., Yang, S., & Banai, R. (2007). Contextual adjustments in cognitive control across tasks. *Psychological Science, 18,* 1040–1043. http://dx.doi.org/10.1111/j.1467-9280.2007.02022.x

Frings, C., & Wentura, D. (2008). Trial-by-trial effects in the affective priming paradigm. *Acta Psychologica, 128,* 318–323. http://dx.doi.org/10.1016/j.actpsy.2008.03.004

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 121,* 480–506.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science, 273,* 1699–1702. http://dx.doi.org/10.1126/science.273.5282.1699

Greenwald, A. G., Klinger, M. R., & Schuh, E. S. (1995). Activation by marginally perceptible ("subliminal") stimuli: Dissociation of unconscious from conscious cognition. *Journal of Experimental Psychology: General, 124,* 22–42. http://dx.doi.org/10.1037/0096-3445.124.1.22

Hazeltine, E., Lightman, E., Schwarb, H., & Schumacher, E. H. (2011). The boundaries of sequential modulations: Evidence for set-level control. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1898–1914. http://dx.doi.org/10.1037/a0024662

Hommel, B., Proctor, R. W., & Vu, K. P. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research, 68,* 1–17. http://dx.doi.org/10.1007/s00426-003-0132-y

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,* 637–651. http://dx.doi.org/10.1016/j.cognition.2013.09.001

Kiesel, A., Kunde, W., & Hoffmann, J. (2006). Evidence for task-specific resolution of response conflict. *Psychonomic Bulletin & Review, 13,* 800–806. http://dx.doi.org/10.3758/BF03194000

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,* 498–503. http://dx.doi.org/10.1037/a0033047

Kouider, S., & Dehaene, S. (2009). Subliminal number priming within and across the visual and auditory modalities. *Experimental Psychology, 56,* 418–433. http://dx.doi.org/10.1027/1618-3169.56.6.418

Kunde, W. (2003). Sequential modulations of stimulus–response correspondence effects depend on awareness of response conflict. *Psychonomic Bulletin & Review, 10,* 198–205. http://dx.doi.org/10.3758/BF03196485

Kunde, W., & Wühr, P. (2006). Sequential modulations of correspondence effects across spatial dimensions and tasks. *Memory & Cognition, 34,* 356–367. http://dx.doi.org/10.3758/BF03193413

Lingnau, A., & Vorberg, D. (2005). The time course of response inhibition in masked priming. *Perception & Psychophysics, 67,* 545–557. http://dx.doi.org/10.3758/BF03193330

Liu, P., Chen, A., Li, C., Li, H., & West, R. (2012). Conflict adaptation is reflected by response interference. *Journal of Cognitive Psychology, 24,* 457–467. http://dx.doi.org/10.1080/20445911.2011.651080

MacDonald, A. W., III, Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288,* 1835–1838. http://dx.doi.org/10.1126/science.288.5472.1835

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict-adaptation effects in the absence of executive control. *Nature Neuroscience, 6,* 450–452.

McBride, J., Boy, F., Husain, M., & Sumner, P. (2012). Automatic motor activation in the executive control of action. *Frontiers in Human Neuroscience, 6*(82), 1–14. http://dx.doi.org/10.3389/fnhum.2012.00082

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science, 13,* 416–424. http://dx.doi.org/10.1111/1467-9280.00474

Naccache, L., Gaillard, R., Adam, C., Hasboun, D., Clémenceau, S., Baulac, M., . . . Cohen, L. (2005). A direct intracranial record of emotions evoked by subliminal words. *PNAS: Proceedings of the National Academy of Sciences of the United States of America, 102,* 7713–7717. http://dx.doi.org/10.1073/pnas.0500542102

Nigbur, R., Cohen, M. X., Ridderinkhof, K. R., & Stürmer, B. (2012). Theta dynamics reveal domain-specific control over stimulus and response conflict. *Journal of Cognitive Neuroscience, 24,* 1264–1274. http://dx.doi.org/10.1162/jocn_a_00128

Notebaert, W., & Verguts, T. (2007). Dissociating conflict adaptation from feature integration: A multiple regression approach. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 1256–1260. http://dx.doi.org/10.1037/0096-1523.33.5.1256

Reuss, H., Desender, K., Kiesel, A., & Kunde, W. (2014). Unconscious conflicts in unconscious contexts: The role of awareness and timing in flexible conflict adaptation. *Journal of Experimental Psychology: General, 143,* 1701–1718. http://dx.doi.org/10.1037/a0036437

Ridderinkhof, K. R. (2002). Micro- and macro-adjustments of task set: Activation and suppression in conflict tasks. *Psychological Research, 66,* 312–323. http://dx.doi.org/10.1007/s00426-002-0104-7

Schmidt, J. R., & De Houwer, J. (2011). Now you see it, now you don't: Controlling for contingencies and stimulus repetitions eliminates the Gratton effect. *Acta Psychologica, 138,* 176–186. http://dx.doi.org/10.1016/j.actpsy.2011.06.002

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron, 79,* 217–240. http://dx.doi.org/10.1016/j.neuron.2013.07.007

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51,* 300–304. http://dx.doi.org/10.1037/h0020586

Soutschek, A., Taylor, P. C., Müller, H. J., & Schubert, T. (2013). Dissociable networks control conflict during perception and response selection: A transcranial magnetic stimulation Study. *The Journal of Neuroscience, 33,* 5647–5654. http://dx.doi.org/10.1523/JNEUROSCI.4768-12.2013

Stins, J. F., Polderman, J. C., Boomsma, D. I., & de Geus, E. J. C. (2007). Conditional accuracy in response interference tasks: Evidence from the Eriksen flanker task and the spatial conflict task. *Advances in Cognitive Psychology, 3,* 409–417. http://dx.doi.org/10.2478/v10053-008-0005-4

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662. http://dx.doi.org/10.1037/h0054651

Stürmer, B., & Leuthold, H. (2003). Control over response priming in visuomotor processing: A lateralized event-related potential study. *Experimental Brain Research, 153,* 35–44. http://dx.doi.org/10.1007/s00221-003-1579-1

Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 1345–1363. http://dx.doi.org/10.1037/0096-1523.28.6.1345

Stürmer, B., Seiss, E., & Leuthold, H. (2005). Executive control in the Simon task: A dual-task examination of response priming and its sup-

pression. *European Journal of Cognitive Psychology, 17,* 590–618. http://dx.doi.org/10.1080/09541440540000077

Ullsperger, M., Bylsma, L. M., & Botvinick, M. M. (2005). The conflict-adaptation effect: It's not just priming. *Cognitive, Affective & Behavioral Neuroscience, 5,* 467–472. http://dx.doi.org/10.3758/CABN.5.4.467

Van den Bussche, E., Notebaert, K., & Reynvoet, B. (2009). Masked primes can be genuinely semantically processed: A picture prime study. *Experimental Psychology, 56,* 295–300. http://dx.doi.org/10.1027/1618-3169.56.5.295

van den Wildenberg, W. P., Wylie, S. A., Forstmann, B. U., Burle, B., Hasbroucq, T., & Ridderinkhof, K. R. (2010). To head or to heed? Beyond the surface of selective action inhibition: A review. *Frontiers in Human Neuroscience, 4,* 222. http://dx.doi.org/10.3389/fnhum.2010.00222

van Gaal, S., Lamme, V. A., & Ridderinkhof, K. R. (2010). Unconsciously triggered conflict adaptation. *PLoS ONE, 5,* e11508. http://dx.doi.org/10.1371/journal.pone.0011508

van Veen, V., & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience, 14,* 593–602. http://dx.doi.org/10.1162/08989290260045837

van Veen, V., Cohen, J. D., Botvinick, M. M., Stenger, V. A., & Carter, C. S. (2001). Anterior cingulate cortex, conflict monitoring, and levels of processing. *NeuroImage, 14,* 1302–1308. http://dx.doi.org/10.1006/nimg.2001.0923

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

Verleger, R., Jaśkowski, P., Aydemir, A., van der Lubbe, R. H. J., & Groen, M. (2004). Qualitative differences between conscious and nonconscious processing? On inverse priming induced by masked arrows. *Journal of Experimental Psychology: General, 133,* 494–515. http://dx.doi.org/10.1037/0096-3445.133.4.494

Vermeiren, A., & Cleeremans, A. (2012). The validity of *d′* measures. *PLoS ONE, 7,* e31595. http://dx.doi.org/10.1371/journal.pone.0031595

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *PNAS: Proceedings of the National Academy of Sciences of the United States of America, 100,* 6275–6280. http://dx.doi.org/10.1073/pnas.0931489100

Wendt, M., Heldmann, M., Münte, T. F., & Kluwe, R. H. (2007). Disentangling sequential effects of stimulus- and response-related conflict and stimulus-response repetition using brain potentials. *Journal of Cognitive Neuroscience, 19,* 1104–1112. http://dx.doi.org/10.1162/jocn.2007.19.7.1104

Wendt, M., Kluwe, R. H., & Peters, A. (2006). Sequential modulations of interference evoked by processing task-irrelevant stimulus features. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 644–667. http://dx.doi.org/10.1037/0096-1523.32.3.644