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Brain mechanisms of unconscious cognitive control

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7. Unconsciously triggered conflict adaptation

Abstract

In conflict tasks such as the Stroop, the Eriksen flanker or the Simon task, it is generally observed that the detection of conflict in the current trial reduces the impact of conflicting information in the subsequent trial; a phenomenon termed conflict adaptation. This higher-order cognitive control function has been assumed to be restricted to cases where conflict is experienced consciously. In the present experiment we manipulated the awareness of conflict-inducing stimuli in a metacontrast masking paradigm to directly test this assumption. Conflicting response tendencies were elicited either consciously (through primes that were weakly masked) or unconsciously (strongly masked primes). We demonstrate trial-by-trial conflict adaptation effects after conscious as well as unconscious conflict, which could not be explained by direct stimulus/response repetitions. These findings show that unconscious information can have a longer-lasting influence on our behavior than previously thought and further stretch the functional boundaries of unconscious cognition.

Introduction

Masked priming studies have revealed a plethora of effects of masked stimuli on behavior and brain activity, highlighting an important role of unconscious information in guiding day-to-day behavior. Masked priming studies also showed that the effects of unconscious stimuli on behavior and brain activity are of a fleeting form. Behavioral priming effects are generally absent when the interval between the masked prime and the target is longer than ~500 ms (Dupoux et al., 2008; Greenwald et al., 1996; Kunde, 2003; Mattler, 2003, 2005) and neuroimaging studies showed a rapid decay of unconsciously triggered neural activations (e.g. Dehaene et al., 2001), often being absent in prefrontal cortex (but see Lau & Passingham, 2007; van Gaal et al., 2008). These results suggest that bridging information across time cannot occur if subjects are not aware of the stimulus (Dehaene & Naccache, 2001). On the other hand, conscious information can be held active for long periods of time and stored in working memory. The combination of these results suggests that conscious information can be used strategically to plan, guide and control future behaviors, whereas unconscious information cannot.

This phenomenon was nicely illustrated by Kunde (2003). In his experiment, participants were required to perform a speeded two-choice response to a target arrow that was preceded by a smaller arrow, the so-called prime. Because the prime

fitted within the contour of the target, the target functioned as a (metacontrast) mask (Breitmeyer, 1984). Therefore, participants were not aware of the prime when it was presented very briefly, whereas it was clearly visible when presented slightly longer. Although a prime could not be perceived it was still processed beyond the visual system, as evidenced by faster response times (RTs) and fewer errors when the prime and target were congruent than when they were incongruent, referred to here as the *correspondence effect* (Kunde, 2003; Vorberg et al., 2003). Interestingly, the conscious experience of response conflict on trial $n-1$ (previous trial) influenced cognitive control mechanisms on trial n (current trial), in such a way that the correspondence effect on trial n was smaller when trials were preceded by an incongruent trial compared to a congruent trial; here referred to as *conflict adaptation*.

These results are generally interpreted by assuming that, following the detection of conflict, PFC-driven cognitive control processes resolve conflict and increase future performance by increasing top-down control over sensory processes (Botvinick et al., 2001; Egner & Hirsch, 2005; Kerns et al., 2004). However, the occurrence of specific stimulus/response repetitions might also explain some (Hommel et al., 2004; Mayr et al., 2003; Nieuwenhuis et al., 2006), but not all of the variance in conflict tasks (e.g. Egner, 2007; Egner & Hirsch, 2005; Ullsperger, Bylsma, & Botvinick, 2005). Crucially, in Kunde's experiment, whereas conflict adaptation was clearly present after the conscious experience of conflict, it was absent when conflict-inducing stimuli were experienced unconsciously, which suggests that conscious information processing is necessary for trial-by-trial regulatory changes in cognitive control.

Here we followed-up on this initial work to test whether it is truly impossible to initiate conflict adaptation unconsciously. In Kunde's experiment a warning sign (a click sound) was presented before the presentation of each prime-target pair, which predicted the upcoming stimulus that was always presented 750 ms later. We reasoned that it might have been possible that participants released their attention after each trial and waited for the warning sign to reinstate their attentional focus. Therefore, the weak neural traces elicited by masked primes might have "died out" before the appearance of the next trial. Indeed, it has been shown that top-down attention facilitates the processing of unconscious information on the current trial (Naccache, Blandin, & Dehaene, 2002; Sumner, Tsai, Yu, & Nachev, 2006). Furthermore, it has been proposed recently that top-down attentional processes might improve the ability to maintain the otherwise fleeting form of information

carried by the unconscious stimulus and that when attention is released the ability to use this information disappears (Gaillard et al., 2009).

To test this prediction, we slightly modified the task design in such a way that the presentation of a prime-target pair was not preceded by a warning sign. Additionally, we decreased the inter-trial interval in the present experiment (now ranging from ~1200 to ~1500 ms instead of ranging from 2050 to 2350 ms) and did not include a neutral condition. The combination of these factors ensured that participants had to continue focusing on the location of the imminent stimulus during the (short) inter-trial interval for fast and accurate performance. Using this version of the masked priming task, we demonstrate trial-by-trial conflict adaptation effects after conscious as well as unconscious conflict.

Method and Materials

Participants

Fifty-eight volunteers participated in a battery of tests (2h) including the one described in the current paper (½h) for course credits or financial compensation. All procedures were executed in compliance with relevant laws and institutional guidelines and were approved by the local ethical committee. Subjects gave written informed consent before experimentation.

Design

Stimuli were presented against a white background at the centre of a 17-inch VGA monitor (frequency 70 Hz.), which was viewed from a distance of approximately 90 cm (each cm subtended a visual angle of 0.64°). A blue prime arrow (width 0.96°, height 0.64°) was presented for 14 ms or 128 ms, followed by a blank interval (28 ms), and then by a target arrow (128 ms, width 2.20°, height 1.47°) that instructed participants to respond as quickly and accurately as possible to its direction (Figure 7.1a). Participants were instructed to ignore the prime, which was a smaller version of the target and fitted within the contour of the target. By manipulating prime duration, the prime was either visible (*weakly masked condition*), or its visibility was sharply reduced (*strongly masked condition*). Thus, four conditions were created: 1) weakly masked incongruent trials, 2) weakly masked congruent trials, 3) strongly masked incongruent trials, and 4) strongly masked congruent trials. Participants performed four blocks, each containing 160 trials (40 per condition, pseudo-randomized). Total trial duration was 1400, 1500, 1600 or 1700 ms (equal frequency). Before the experiment participants practiced the task briefly (32 trials).

After the main task, participants performed a two-alternative forced-choice discrimination task on the primes (80 trials; 20 trials of each condition). Stimulus and trial timing was exactly the same as in the main task, except that a pair of choices was presented left and right of fixation after each trial. Participants were asked to determine as accurately as possible whether a left-pointing or right-pointing prime was presented in the preceding trial. Before administering this task, participants were told that left and right pointing primes were presented equally frequently and were instructed to consider this in giving their response. Accuracy was important in this task, not the speed of responding. Upon responding a new trial started.

Data analysis

RTs < 100 and > 1000 were excluded from the analysis. Mean RTs on correct trials and square rooted accuracy rates on congruent/incongruent trials were entered in to an ANOVA with within-subjects' variable of prime-target correspondence in the previous trial (congruent vs. incongruent) and masking strength (weakly vs. strongly masked). Detection performance (percentage correct) was tested for significance for each individual participant using a binominal test evaluated at an alpha level of 0.05.

Results

The two-alternative forced-choice discrimination task administered after the main task revealed that 42 out of 58 (72%) participants were unable to perceive the strongly masked primes, as evidenced by chance-level performance (binominal test). Because we cannot ascertain that the other 16 participants were truly unable to perceive the strongly masked primes consciously, they were excluded from further analyses. For the remaining 42 participants the percentage correct for weakly masked primes was 91.8% (SD = 12.6) vs. 54.8% (SD = 5.7) for strongly masked primes. Although discrimination performance for the strongly masked primes was close to 50%, on a group level, it was slightly above chance-level ($t(41) = 5.46, p < 0.001$).

Overall, participants responded slower to incongruent than to congruent trials (main effect of current trial, $F(1,41) = 315.52; p < 0.001$) and also slower after experiencing conflict in the previous trial (main effect of previous trial, $F(1,41) = 67.96; p < 0.001$). Conflict adaptation was highly significant (interaction current*previous, $F(1,41) = 67.55; p < 0.001$) and was stronger for weakly masked than strongly masked primes (3-way interaction current*previous*masking strength; $F(1,41) = 13.74; p < 0.001$). Participants made more errors on incongruent than congruent trials ($F(1,41) = 111.75; p < 0.001$) and fewer errors after the

experience of conflict in the previous trial ($F(1,41) = 86.89; p < 0.001$). Again, conflict adaption was significant ($F(1,41) = 68.18; p < 0.001$) and more pronounced for weakly than strongly masked primes ($F(1,41) = 39.92; p < 0.001$).

Follow-up analyses revealed significant RT conflict adaptation for weakly masked primes ($F(1,41) = 57.66, p < 0.001$). Crucially, this was also the case for strongly masked primes ($F(1,41) = 8.02, p = 0.007$). The error analysis confirmed that conscious ($F(1,41) = 67.69, p < 0.001$) as well as unconscious conflict ($F(1,41) = 5.72, p = 0.021$) in the preceding trial led to conflict adaptation in the current trial (see Figure 7.1b).

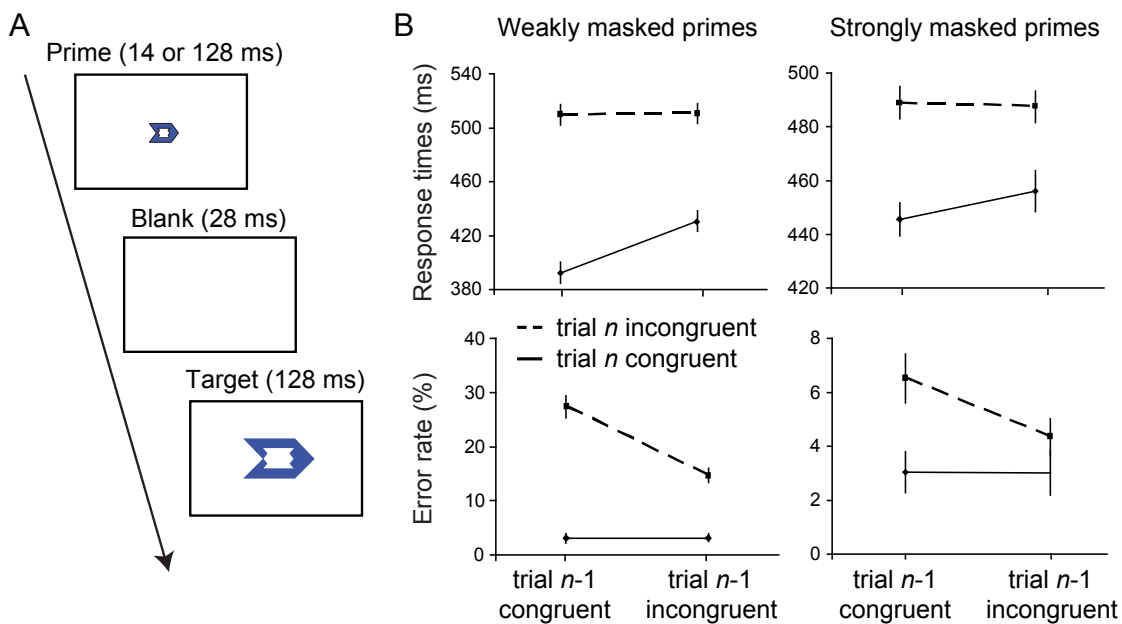


Figure 7.1 Experimental design and conflict adaptation results

a) Stimuli and trial timing. b) Mean RT and error rates as a function of prime-target correspondence in trial n (congruent vs. incongruent), prime-target correspondence in trial $n-1$ and masking strength (weak vs. strong masking). Conflict adaptation was significant for weakly (left panel) and strongly masked primes (right panel); RTs (upper panel), error rates (lower panel). Note that the conflict adaptation effects were significantly larger for weakly masked primes than for strongly masked primes.

It is controversial whether these conflict adaptation effects are truly due to regulatory changes in cognitive control or whether they reflect mere lower-level priming effects (Hommel, 2004; Mayr et al., 2003). It has been argued that, especially in the Eriksen Flanker task, conflict adaptation effects might be mediated by particularly fast responses on trials preceded by trials with the same stimulus/response contingencies, especially evident for congruent trials following congruent trials and incongruent trials following incongruent trials with the same

response. To test this issue, we re-analyzed the data in such a way that in one subset of the data all trials with direct stimulus/response repetitions were excluded (*change trials*), whereas in a second subset *only* trials with direct stimulus/response repetitions were included (*repetition trials*). The correspondence effect for RTs and errors as a function of prime-target correspondence in the preceding trial is depicted in figure 7.2. Conflict adaptation was highly similar across change and repetition trials, as evidenced by the absence of a 3-way interaction between current*previous*dataset for RTs ($F(1,41) = 0.74$; $p = 0.395$) as well as errors ($F(1,41) = 0.25$; $p = 0.618$), which suggests that conflict adaptation was not due to low-level priming effects.

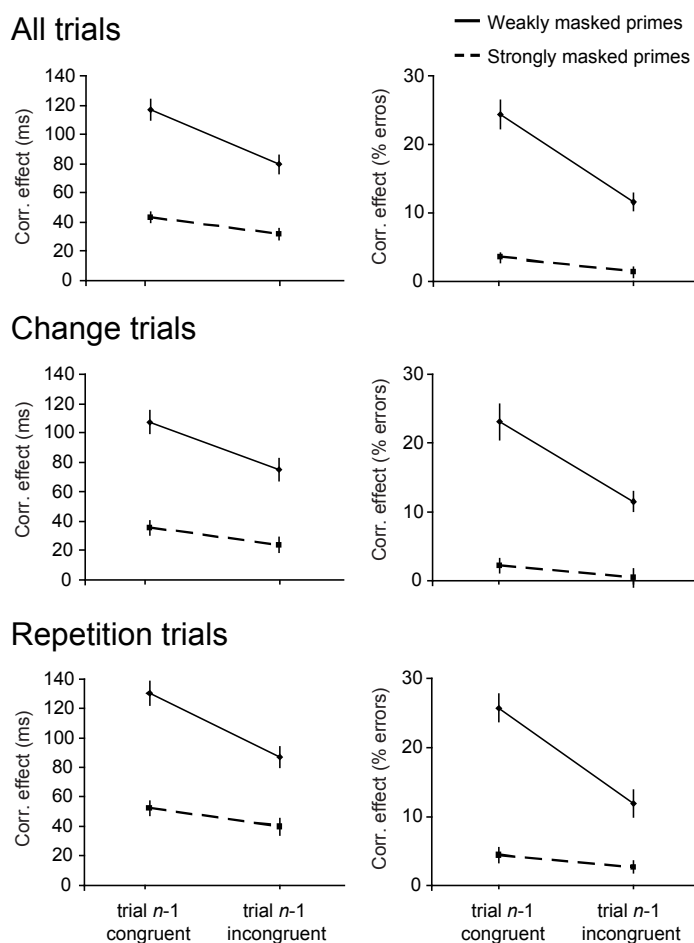


Figure 7.2 Correspondence effects for consciously and unconsciously induced conflict

Correspondence effect in trial n for RTs (mean RT on incongruent trials – mean RT on congruent trials, left panel) and error rates (mean percentage of errors on incongruent trials – mean percentage of errors on congruent trials, right panel) as a function of correspondence in trial $n-1$ and masking strength (weak vs. strong masking). Correspondence effects are reported for a dataset containing all trials (upper panel), trials without stimulus/response repetitions (*change trials*, middle panel) and trials with stimulus/response repetitions only (*repetition trials*, lower panel).

Prime visibility and adaptive control

To rule out the possibility that the conflict adaptation effects observed on strongly masked primes were due to incidental visibility of the primes, we performed several additional analyses. First, we correlated the conflict adaptation effect on strongly masked primes with detection performance (percentage correct) on these trials across participants to check whether both measures are related. Conflict adaptation effects (RTs or error rates) did not correlate significantly with detection performance (both $ps > 0.8$). Additionally, we selected the 50% (21 participants) worst detection performers (mean percentage correct = 50.1%) and tested conflict adaptation across these “poor detectors”. Within this group, unconscious conflict adaptation effects were still significant for RTs ($F(1,20) = 4.717, p = 0.042$) and (marginally) significant for error rates ($F(1,20) = 3.418, p = 0.079$). These additional analyses suggest that it is unlikely that the unconscious conflict adaptation effects were due to accidental visibility of the primes.

Discussion

We report that unconsciously induced conflict can initiate trial-by-trial cognitive control operations (conflict adaptation), commonly assumed to require consciousness (Dehaene & Naccache, 2001; Kunde, 2003). In a masked priming experiment, we focused on behavioral adaptations following conflict resulting from incongruent trials compared to behavioral adaptations after trials on which no conflict was experienced (congruent trials). Conflicting response tendencies were elicited either consciously (weakly masked primes) or unconsciously (strongly masked primes). We replicated the standard conflict adaptation effect for conscious conflict; the correspondence effect was sharply reduced after incongruent compared to congruent trials (for response times as well as error rates). Crucially, conflict adaptation was also present after unconsciously induced conflict. These findings suggest that participants engender a more cautious response strategy and increase cognitive control after the experience of conscious, but also unconscious conflict-inducing stimuli to prevent future errors.

Generally, conflict adaptation is interpreted by assuming that, following conflict, cognitive control processes subserved by the prefrontal cortex resolve conflict and increase future performance by increasing top-down control over perceptual processes (Botvinick et al., 2001; Egner & Hirsch, 2005; Kerns et al., 2004). However, it has also been argued that correspondence effects can be explained fully by low-level repetition priming effects (Hommel et al., 2004; Mayr et al., 2003). Although repetition priming has been shown to explain variance on some

occasions (Mayr et al., 2003; Nieuwenhuis et al., 2006), the present as well as several previous results could not be explained by simple stimulus/response repetitions across trials (e.g. Egner & Hirsch, 2005; Ullsperger et al., 2005).

Interestingly, using a similar design, Kunde (2003) did not observe conflict adaptation after unconscious conflict. The crucial difference between his design and ours is the omission of a warning sign before stimulus presentation along with shorter trial durations in the present experiment. We argue that these two manipulations ensured that participants remained their attentional focus in between trials, instead of releasing their attention up until the presentation of the warning sign. Since it has been shown recently that (spatial and temporal) attention can be oriented towards unconscious stimuli and increases the impact of these stimuli on subsequent behavior (Naccache et al., 2002; Sumner et al., 2006), we hypothesize that, in line with others (Gaillard et al., 2009), such relatively long-term effects of unconscious information might be due to top-down attentional facilitation of the weak neural traces elicited by the unconscious primes.

Although speculative since we did not obtain any neural measures here, recent studies did observe relatively long-lasting neural activations elicited by masked (unconscious) words in a masked priming paradigm, up to approximately one second (Gaillard et al., 2009; Naccache et al., 2005). Even longer effects of unconscious priming (up to several minutes) have been reported, for example in “mere exposure” paradigms (Elliott & Dolan, 1998; Gaillard et al., 2007). In combination, these results suggests that unconscious stimuli can influence cognitive processes for longer periods of time than previously thought, which has direct implications for theoretical models that propose a rapid decay of unconscious neural traces (Dehaene et al., 2006; Kouider & Dehaene, 2007; Rossetti, 1998). Future studies are necessary to further specify the temporal limitations of unconscious information processing, for example by systematically varying the inter-trial interval in a masked priming experiment.

In sum, we show that unconsciously experienced conflict-inducing stimuli can trigger conflict adaptation. These results add to the growing body of literature suggesting that unconscious information can be used for high-level (prefrontal) cognitive control functions, such as inhibitory control (van Gaal et al., 2008), task switching (Lau & Passingham, 2007) and adaptive regulatory cognitive control (present study). These results further elucidate and expand the potential influence of unconscious information on our direct, but also future decisions.