Cogn Affect Behav Neurosci (2015) 15:251–261
DOI 10.3758/s13415-014-0318-3

No pain, no gain: the affective valence of congruency conditions changes following a successful response

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Published online: 3 September 2014

Abstract The cognitive control theory of Botvinick, *Cognitive, Affective, & Behavioral Neuroscience, 7,* 356–366 (2007) integrates cognitive and affective control processes by emphasizing the aversive nature of cognitive conflict. Using an affective priming paradigm, we replicate earlier results showing that incongruent trials, relative to congruent trials, are indeed perceived as more aversive (Dreisbach & Fischer, *Brain and Cognition, 78*(2), 94–98 (2012)). Importantly, however, in two experiments we demonstrate that this effect is reversed following successful responses; correctly responding to incongruent trials engendered relatively more positive affect than correctly responding to congruent trials. The results are discussed in light of a recent computational model by Silvetti, Seurinck, and Verguts, *Frontiers in Human Neuroscience*, 5:75 (2011) where it is assumed that outcome expectancies are more negative for incongruent trials than congruent trials. Consequently, the intrinsic reward (prediction error) following successful completion is larger for incongruent than congruent trials. These findings divulge a novel perspective on 'cognitive' adaptations to conflict.

Keywords Cognitive control · Conflict · Affective priming · Reward prediction error · Intrinsic reward · Conflict adaptation · Anterior cingulate cortex

Introduction

Over the last few decades, cognitive control research developed from 'cold' theories of cognitive control (e.g., Atkinson & Shiffrin, 1968; Norman & Shallice, 1986) to models integrating cognition and emotion (e.g., Botvinick, 2007; Verguts & Notebaert, 2009). This trend is further supported by numerous neuroimaging studies, showing for instance how the anterior cingulate cortex (ACC) - thought to play a central role in cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001) - is also involved in emotion processing and affect regulation (Shackman et al., 2011).

Cognitive control studies typically use congruency tasks to investigate the processing of and adaptations to conflict. In these tasks, conflict is induced by a competition between task-relevant dimensions and irrelevant to-be-ignored stimulus features. For instance, in the Stroop task (Stroop, 1935), detecting the ink color of a word (relevant dimension) is facilitated when the meaning of the word (irrelevant dimension) and ink color correspond (congruent trials, e.g., 'RED' in red ink), whereas it is hindered when the word meaning and ink color interfere (incongruent trials, e.g., 'RED' in blue ink). This is because incongruent trials induce a cognitive conflict, which has recently been suggested to be aversive or negative in nature (Botvinick, 2007).

Several recent studies support the aversive nature of conflict. Schouppe, De Houwer, Ridderinkhof, and Notebaert (2012), for instance, showed a reduction of the stimulus

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congruency effect when participants had to avoid, relative to approach, a Stroop stimulus, suggesting that in the face of conflict, avoidance is the more likely response. Similarly, Cannon, Hayes, and Tipper (2010) found that congruent stimuli evoked greater activity of the zygomaticus muscle (associated with smiling) than incongruent stimuli. Perhaps most convincingly, Dreisbach and Fischer (2012) recently used an affective priming paradigm (Fazio, 2001) to demonstrate the negative affective nature of conflict. In this task, participants had to evaluate positive and negative words that were preceded by congruent or incongruent Stroop primes (see also Brouillet, Ferrier, Grosselin, & Brouillet, 2011; Fritz & Dreisbach, 2013). Interestingly, the categorization of negative, relative to positive, words was facilitated following incongruent, relative to congruent, Stroop primes.

In their reward value and prediction model (RVPM) of the ACC, Silvetti, Seurinck, and Verguts (2011) provided a neurocomputational account for the affective connotation of conflicting situations. They proposed that incongruent trials, relative to congruent trials, evoke negative prediction error signals (negative surprises) in the ACC due to their longer reaction times and higher error probability (see also Alexander & Brown, 2011). Over time, these recurring experiences of negative prediction errors during incongruent trials add up to an overall lowered success (or reward) expectancy for incongruent trials, relative to congruent trials. Interestingly, the RVPM also predicts that once an incongruent trial is correctly solved, this will evoke a positive prediction error signal (positive surprise) that is larger than on congruent trials. It has been shown that such positive prediction errors are tightly correlated with mesolimbic activation (Schultz, 1998), including the subcortical regions related to pleasure and/or emotion (Berridge & Kringelbach, 2013). The model thus predicts a shift from a negative signal to a positive signal following conflict resolution (i.e., responding correctly to an incongruent stimulus), and interprets the conflict-related ACC activation as the conjoined effect of both negative and positive prediction error signals.

Hence, the model predicts that cognitive tasks can induce both negative and positive evaluative signals. In line with this idea, Molapour and Morsella (2011) demonstrated that nonsense shapes that co-occurred with incongruent Stroop stimuli were preferred over shapes that co-occurred with congruent or neutral Stroop stimuli. Crucially, and in contrast to the study of Dreisbach and Fischer (2012), participants had to respond to each Stroop stimulus. As predicted by Silvetti et al. (2011), conflict resolution results in a positive affective state, which could transfer to the shapes that were paired with incongruent Stroop stimuli. However, the findings of Molapour and Morsella provide at best indirect evidence for the potentially rewarding role of conflict resolution. We therefore set out to examine this issue more directly.

In our first experiment, we aimed to replicate the findings of Dreisbach and Fischer (2012) using a combination of a flanker task (Eriksen & Eriksen, 1974) and an affective priming task. Similar to Dreisbach and Fischer, congruent or incongruent flanker stimuli (primes) did not require a response. We predicted that incongruent, relative to congruent primes, would facilitate responding to negative targets. In Experiment 2A, participants did respond to the congruent or incongruent flanker stimulus before making an affective judgment. In this case, we predicted incongruent primes, relative to congruent primes, to facilitate responding to positive targets, because the conflict elicited by the incongruent primes had to be resolved. In Experiment 2B, we aimed at extending our paradigm to a four-color Stroop task, allowing us to investigate if this positive affective priming effect would generalize to different types of conflict (resolution).

Experiment 1

Method

Participants

Twenty students at Ghent University initially participated in the study. Due to a misunderstanding of the response mapping instructions (as indicated by an error rate of more than 45 %), the data of seven participants were removed from the analyses. A systematic misunderstanding of the response mapping in the affective judgment task is possible because no training phase and no online feedback was provided. To ensure a correctly balanced design, seven additional participants were tested, resulting in 20 participants eligible for analyses (all right-handed; 18–23 years old; three men). All participants provided written informed consent and were paid or received course credits in return for participation.

Stimuli

The primes were flanker stimuli consisting of a vertical array of five arrows. The direction of the central arrow could either match (congruent prime) or mismatch (incongruent prime) the direction of the neighbouring arrows. Target stimuli (see Table 1 of Aarts, De Houwer, & Pourtois, 2012) were positive and negative words, selected on the basis of a normative study involving affective ratings of 700 Dutch words (Hermans & De Houwer, 1994).

Procedure

Participants were told that their main task was to evaluate the valence of words that were preceded by flanker stimuli. Each trial started with a fixation cross for 500 ms, followed by a flanker stimulus for 400 ms, after which the affective word appeared. The affective word remained on the screen until a response was given. The inter-trial interval was 1000 ms (see Fig. 1).

The experiment consisted of two experimental blocks of 360 trials, intermixed with self-paced breaks every 90 trials. In each block, each of the 60 words was paired four times with a congruent flanker stimulus and twice with an incongruent stimulus. This frequency manipulation was adopted to increase the conflict elicited by an incongruent stimulus (Tzelgov, Henik, & Berger, 1992). To ensure that participants were aware of the conflict elicited by the incongruent flanker stimulus, a practice block of 40 trials involving only flanker stimuli (50 % congruent, 50 % incongruent) preceded each experimental block (cf. Dreisbach & Fischer, 2012). In this practice block, a trial started with a fixation cross for 500 ms, after which a flanker stimulus appeared. This stimulus remained on the screen until a response was given or until a response deadline of 1000 ms was exceeded. The inter-trial interval was 1000 ms.

Each task (the flanker task and the affective judgment task) was assigned to a different hand. The task-to-hand mapping was counterbalanced across participants. When performing the affective judgment task with their left hand, participants pressed the 'D' key for positive words and the 'S' key for negative words. When using their right hand, they pressed the 'L' key for positive words and the 'K' key for negative words. In the flanker task, participants pressed the 'E' or 'D' key with their left hand (or 'I' or 'K' key with their right hand) when the central arrow pointed upwards or downwards respectively.

Results

Affective priming task

Mean reaction times (RTs) and error rates for responses to the target words were analyzed using a 2 × 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent) and target valence (positive vs. negative) as within-subjects factors. The first trial after each break was omitted. Also, trials following an error were excluded to avoid interfering effects of errors on the affective judgment task (Aarts et al., 2012). For the RT analysis, errors (5 %) were discarded. Also, trials with responses faster than 200 ms or slower than 2000 ms (<1 %) were excluded. For the error analysis, we used the arc sine square root transformation of the percentage of incorrect responses. This transformation was also used for the error analyses of Experiment 2A and 2B.

Reaction times We found a significant interaction between target valence and prime congruency, $F(1, 19) = 4.52$, $p < .05$, $\eta_p^2 = .19$. As depicted in Fig. 2, this interaction indicated faster responses on positive targets, relative to negative targets, when preceded by a congruent flanker compared to an incongruent flanker. The main effects of prime congruency and target valence were not significant (all ps > .1).

Error rates In the analysis of the error rates, there was a marginally significant main effect of target valence, $F(1, 19) = 4.0$, $p = .061$, $\eta_p^2 = .173$, and a significant main effect of prime congruency, $F(1, 19) = 7.6$, $p < .05$, $\eta_p^2 = .29$, indicating more errors on positive words and after congruent primes respectively. The interaction effect was not significant, $F(1, 19) < 1$, $\eta_p^2 = .008$.

Discussion

Using a similar procedure as Dreisbach and Fischer (2012), we replicated the main finding of an interaction between prime congruency and target valence. The interaction indicates affective priming in the sense that incongruent stimuli (relative to congruent stimuli) prime responses to negative (relative to positive) targets.

Experiment 2A

In Experiment 2A, we tested whether a different affective priming pattern would emerge when participants successfully responded to the prime stimuli by indicating the direction of the central arrow.

Method

Participants

Twenty students at Ghent University participated in Experiment 2A. Due to a misunderstanding of the instructions (as indicated by an error rate of more than 45 %), the data of three participants could not be used for analyses. To ensure a correctly balanced design, three additional participants were tested, resulting in 20 participants eligible for analyses (all right-handed; 18-26 years old; two men). All participants provided written informed consent and were paid or received course credits in return for their participation.

Procedure

Stimuli and trial procedure of Experiment 2A were identical to Experiment 1, except that participants first responded to the direction of the central arrow of the prime stimulus within a 1000 ms response deadline, before performing the affective judgment task (see Fig. 1). The same response keys were used as in Experiment 1. The response to the prime stimuli and the response to the target stimuli were assigned to different hands.

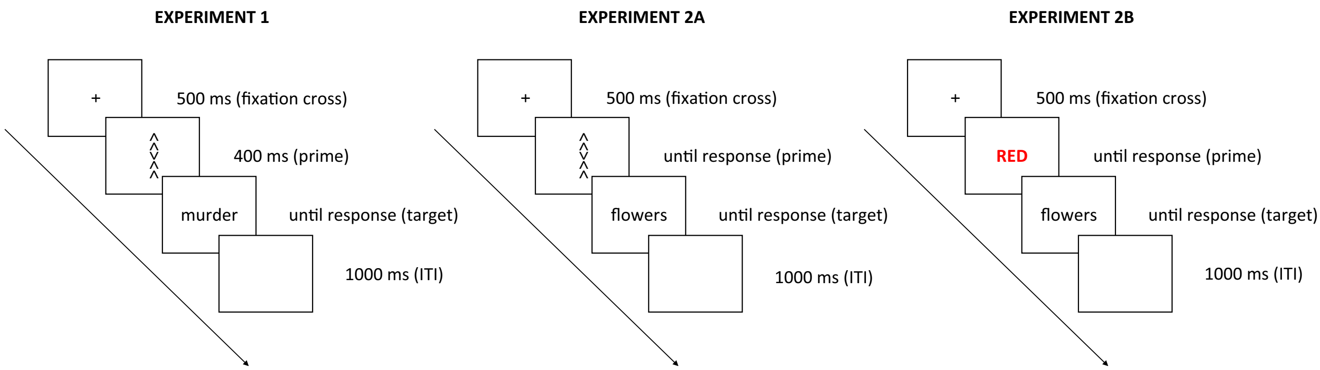

Fig. 1 Trial procedure for Experiment 1 (left panel), Experiment 2A (middle panel) and Experiment 2B (right panel)

This task-to-hand mapping was counterbalanced across participants.

Two experimental blocks of 360 trials were administered. The same frequency of congruency manipulation as in Experiment 1 was adopted. To ensure that participants understood the double task instructions, they could first familiarize themselves with the experiment in a practice block of 24 trials. None of the target words used for these practice trials occurred in the experimental blocks.

Results

Prime task

Practice trials, first trials after each break, and trials with RTs shorter than 200 ms were excluded. For the RT analysis, erroneous responses were discarded. RTs were faster on congruent trials (541 ms) compared to incongruent trials (643 ms), thus revealing a significant congruency effect of 102 ms, $t(19) = 11.9$, $p < .001$, $\eta_p^2 = .88$. Overall, mean accuracies were 94 %. The error rates also demonstrated a significant congruency effect of 4.2 % (5.4 % on incongruent trials vs. 1.2 % on congruent trials), $t(19) = 5.8$, $p < .001$, $\eta_p^2 = .64$.

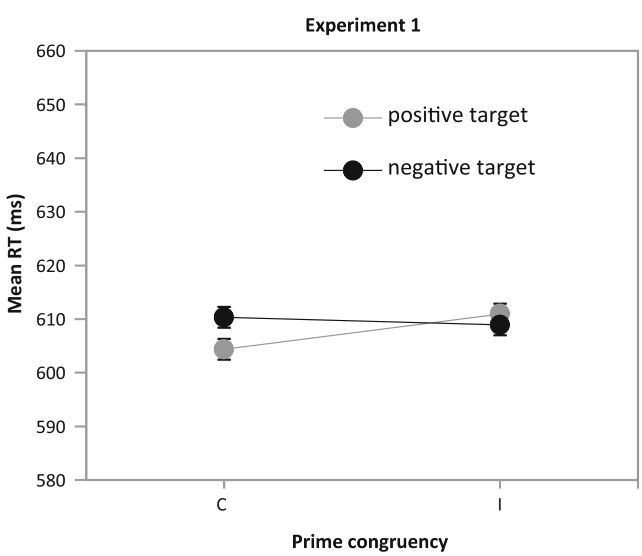

Fig. 2 Mean reaction times (RT) for negative and positive word judgments after congruent (C) and incongruent (I) primes for Experiment 1. Error bars are based on the mean square error of the interaction term (Loftus & Masson, 1994)

Affective priming task

To counter an explanation in terms of varying prime-to-target intervals (i.e., the prime-to-target interval is systematically larger for the incongruent condition compared to the congruent condition), we analyzed the data with prime RT (50 % fastest vs. 50 % slowest responses) as an additional factor in the design. If the prime-to-target interval drives the priming effect, rather than prime congruency, we would expect an interaction between prime RT and valence where relatively fast prime RTs (whether congruent or incongruent) would have to produce negative priming. Mean RTs and error rates for responses on the target words were analysed using a 2 × 2 × 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent), target valence (positive vs. negative), and prime RT (50 % fastest vs. 50 % slowest prime responses; based on a median split on prime RTs for each congruency condition separately) as within-subjects factors. Practice trials, the first trial after each break, and the first trial following an erroneous response were excluded. For the RT analysis, errors (9 % target errors and 6 % prime errors) were also discarded. Also, trials faster than 200 ms or slower than 2000 ms (2 %) were excluded.

Reaction times Target RTs showed a main effect of prime RT, $F(1, 19) = 65.8$, $p < .001$, $\eta_p^2 = .78$. Targets preceded by a fast prime response were responded to faster than targets preceded by a slow prime response. Also a marginally significant interaction between prime congruency and prime RT was found, $F(1, 19) = 4.4$, $p = .050$, $\eta_p^2 = .19$, indicating a larger effect of prime congruency on target RTs when the target was preceded by a fast prime response compared to a slow prime response. Most importantly, the interaction between target valence and prime congruency was significant, $F(1, 19) = 5.1$, $p < .05$, $\eta_p^2 = .21$, demonstrating that participants responded faster on negative targets, relative to positive targets, when preceded by a congruent flanker compared to an incongruent flanker (see also Fig. 3). No other main and interaction effects were significant (all *p*s > .1). Crucially, the interaction between target valence and prime RT was not significant, $F(1, 19) = 1.3$, $p > .1$, suggesting that variability in prime-to-target interval did not influence responses to positive and negative targets. Moreover, the interaction between target valence, prime congruency, and prime RT was not significant, $F(1, 19) < 1$, indicating that the prime-to-target interval did not modulate the affective priming effect.[1]

Importantly, the interaction effect between target valence and prime congruency is different from the affective priming effect observed in Experiment 1 and Dreisbach and Fischer's study (2012). This is demonstrated by the 2 (prime congruency: congruent vs. incongruent) × 2 (target valence: positive vs. negative) × 2 (Experiment: 1 vs. 2A) repeated-measures ANOVA on mean RTs, showing a significant three-way interaction between target valence, prime congruency and experiment, $F(1, 38) = 8.9$, $p < .01$, $\eta_p^2 = .19$.

Error rates The error rates showed a main effect of target valence, $F(1, 19) = 4.8$, $p < .05$, $\eta_p^2 = .20$, indicating more errors on trials with positive targets compared to trials with negative targets. All other main and interaction effects were not significant, all *p*s > .1.

Discussion

The results of Experiment 2A showed that correctly responding to incongruent trials engendered relatively more positive affect than correctly responding to congruent trials, consistent with the hypothesis that conflict resolution is associated with positive affect. Our demonstration of a positive affective priming effect after responding to incongruent relative to congruent primes was also considered in light of an alternative explanation. Specifically, as there was a congruency effect of 102 ms in prime RTs, the average prime-target interval was approximately 100 ms shorter for congruent trials. Importantly, the binary factor prime RT (with fast and slow prime trials that were separated on average 154 ms apart) did not show an influence on the priming effect, yielding an explanation in terms of merely different prime-target intervals unlikely. Similarly, controlling for individual differences in mean prime RT did not affect the significance of our observed affective priming effect.

[1] As an extra check we also conducted an additional 2 (prime congruency) x 2 (target valence) repeated measures ANOVA with individuals' standardized mean prime RT as a covariate. We observed no significant three-way interaction between mean prime RT, target valence and prime congruency, $F < 1$, while the two-way interaction between prime congruency and target valence remained significant, $F(1, 18) = 5.2$, $p < .05$.

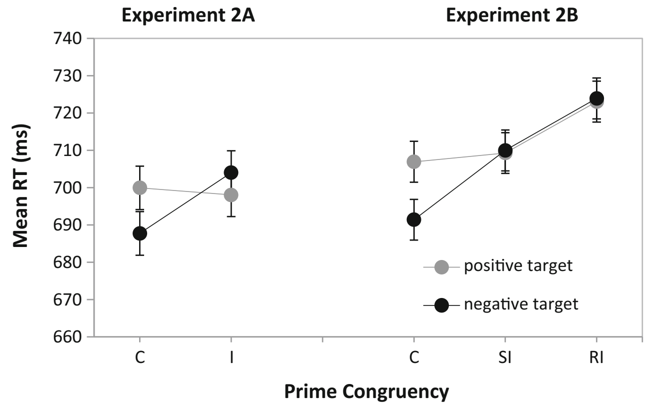

Fig. 3 Mean reaction times (RT) for negative and positive word judgments after congruent (C) and incongruent (I) primes (Experiment 2A) and after congruent (C), stimulus incongruent (SI), and response incongruent (RI) primes (Experiment 2B). Error bars are based on the mean square error of the interaction term (Loftus & Masson, 1994)

Experiment 2B

We replicated the original observation of Dreisbach and Fischer (2012) in a flanker task, showing how incongruent stimuli, relative to congruent stimuli, can induce a negative affective priming effect (Experiment 1), suggesting that cognitive conflict is aversive. In Experiment 2A, we demonstrated that this effect turns into a positive affective priming effect for incongruent primes compared to congruent primes when participants respond to the prime stimuli. In this follow-up Experiment 2B, we aimed at replicating the positive affective priming effect after conflict resolution, using a four-color Stroop task. By testing our hypothesis in a Stroop task, we were able to directly link back to the original observation of Dreisbach and Fischer (2012), who showed a negative affective priming effect after merely observing incongruent Stroop primes, compared to congruent Stroop primes. A reversed priming effect after responding to the Stroop primes would validate our conclusion that conflict resolution results in positive affect. Moreover, by mapping four colors to two responses we could distinguish between: (1) congruent (C) trials, in which the color and the meaning of the word matched, (2) stimulus incongruent (SI) trials, in which the color and the meaning of the word mismatched, but activated the same response, and (3) response incongruent (RI) trials, in which the color and the meaning of the word mismatched, and also activated a different response. SI and RI trials have been demonstrated to have dissociable effects on behavior (e.g., Notebaert & Verguts, 2006; Schouppe et al., 2012) and brain activity (e.g., Van Veen & Carter, 2005). However, it is equally likely that both have a similar effect on our affective priming task, since both types induce a cognitive conflict that needs to be resolved for efficient task performance.

Method

Participants

Thirty-two students at Ghent University initially participated. Given the effect size of the valence × congruency interaction effect observed in Experiment 2A (d = 0.51), we calculated using G-Power (Faul, Erdfelder, Lang, & Buchner, 2007) that 32 participants were needed to obtain 80 % power. Due to a misunderstanding of the instructions (as indicated by an error rate of more than 45 %), the data of four participants could not be used for analyses. To ensure a correctly balanced design, four additional participants were tested, resulting in 32 participants eligible for analyses (all right-handed; 17-31 years old; six men). All participants provided written informed consent and were paid or received course credits in return for their participation.

Stimuli

Prime stimuli now consisted of the Dutch words ‘BLAUW’, ‘GROEN’, ‘ROOD’, or ‘GEEL’ (meaning blue, green, red, or yellow), presented in uppercase letters in a blue, green, red, or yellow font color. Target stimuli were the same as in the preceding experiments.

Procedure

Experiment 2B was similar to Experiment 2A, except that the prime conflict task was now a four-color Stroop task, instead of an arrow flanker task. In a Stroop task, participants are instructed to respond to the ink color of a word, while ignoring its meaning. We used a Stroop task where four colors were mapped onto two responses (see De Houwer, 2003; Schouppe et al., 2012; Van Veen & Carter, 2005). For example, in one response mapping, participants were instructed to press the upper button when the ink color was red or yellow, and the lower button when the color was blue or green (stimuli-set to button assignment was counterbalanced across participants). In this way, we can create SI and RI stimuli. The former are stimuli where the ink color differs from the color word, but both colors are associated with the same response (e.g., the word ‘RED’ in yellow ink). In the latter, ink color again differs from the color word, but now both colors are associated with a different response (e.g., the word ‘RED’ in blue). One-third of the trials were SI trials, another third of the trials were RI trials, and the final third of the trials were C trials, where the ink color of the word corresponded to its meaning (e.g., ‘RED’ in red). To keep the possible stimulus combinations (combining stimulus color and word meaning) constant across conditions (four per congruency type), only a subset of the eight possible RI stimuli was used. This subset was counterbalanced across participants. The trial procedure was identical to Experiment 2A, except that participants now first responded to the ink color with no response deadline, before performing the affective judgment task. The same response keys were used as in the preceding experiments. The response to the prime stimuli and the response to the target stimuli were assigned to different hands. This task-to-hand mapping was also counterbalanced across participants. Altogether, each participant was randomly assigned to one of the eight versions of this experiment (counterbalancing stimuli-set to button assignment, task-to-hand mapping, and subset RI stimuli).

Two experimental blocks of 360 trials were administered, intermixed with self-paced breaks every 90 trials. To ensure that participants understood the double task instructions, they could first familiarize themselves with the experiment in a practice block of 24 trials. None of the target words used for these practice trials reappeared in the experimental blocks.

Results

Prime task

Practice trials, first trials after each break, and trials with RTs shorter than 200 ms were excluded. For the RT analyses, erroneous responses were also discarded. RTs showed an increase from C trials to SI trials to RI trials. C trials (737 ms) were significantly faster than SI trials (765 ms), $t(31) = 4.6$, $p < .001$, $\eta_p^2 = .41$ and RI trials (811 ms), $t(31) = 7.3$, $p < .001$, $\eta_p^2 = .63$. Moreover, RTs on SI trials were significantly faster than on RI trials, $t(31) = 4.7$, $p < .001$, $\eta_p^2 = .42$. Overall, mean accuracy for the prime task was 96 %. More errors were made on RI trials (5.3%) compared to C trials (3.4%), $t(31) = 3.9$, $p < .001$, $\eta_p^2 = .33$, and SI trials (2.8%), $t(31) = 5.1$, $p < .001$, $\eta_p^2 = .46$. Error rates did not differ significantly between C and SI trials, $t(31) = 1.1$, $p > .1$, $\eta_p^2 = .04$.

Affective priming task

Mean RTs and error rates for responses on the target words were analysed using a 3 × 2 × 2 repeated-measures ANOVA with prime congruency (C, SI, RI), target valence (positive vs. negative), and prime RT (50 % slowest vs. 50 % fastest) as within-subjects factors. Practice trials, the first trial after each break and the first trial following an erroneous response were excluded. For the RT analyses, errors (7 % target errors and 4 % prime errors) were also discarded. Also, trials faster than 200 ms and slower than 2000 ms (1 %) were excluded. Greenhouse-Geisser corrections to the p-values are used when the sphericity assumption was violated, but uncorrected degrees of freedom are reported for ease of reading.

Reaction times RTs showed a main effect of prime RT, $F(1, 31) = 164.2$, $p < .001$, $\eta_p^2 = .84$, and a main effect of prime congruency, $F(2, 62) = 14.2$, $p < .001$, $\eta_p^2 = .31$. Furthermore, the interaction between target valence and prime congruency was significant, $F(2, 62) = 3.3$, $p < .05$, $\eta_p^2 = .10$ (see Fig. 3). All other main and interaction effects were not significant (all *p*s > .1). Importantly, neither the interaction between prime RT and target valence, $F(2, 62) < 1$, nor the interaction between prime RT, target valence, and prime congruency were significant, $F(2, 62) = 2.1$, $p > .1$, therefore discarding an interpretation in terms of varying prime-to-target intervals.[2]

The target valence × prime congruency interaction was further investigated using contrast analyses. There was no priming effect for RI over SI trials, $F(1, 31) < 1$. The positive priming effect for SI primes relative to C primes was significant, $F(1, 31) = 6.6$, $p < .05$, $\eta_p^2 = .18$. Similarly, there was a positive affective priming effect for RI primes relative to C primes, $F(1, 31) = 4.6$, $p < .05$, $\eta_p^2 = .13$.

Error rates There were no significant main or interaction effects in the error rates, all *p*s > .1.

Discussion

Using an affective priming procedure where Stroop stimuli served as primes, Dreisbach and Fischer (2012) recently demonstrated the negative nature of incongruent stimuli. In Experiment 2B, we used a similar procedure to Dreisbach and Fischer, with the only exception that participants were first asked to respond to the Stroop stimuli before making an affective judgment. Compared to Experiment 1, the results of Experiment 2B showed a reversed affective priming effect, thereby replicating the results of Experiment 2A and confirming our conclusion that conflict resolution, relative to resolving non-conflict trials, engendered relatively more positive affect. Moreover, we showed that resolving both stimulus and response conflict induced this affective state.

Again, we could establish that this result was not driven by the varying prime-target intervals. Including the binary factor prime RT in the analysis did not yield a significant prime RT × target valence interaction, nor a significant prime RT × target valence × prime congruency interaction. Also, when including individual differences in prime duration as a covariate in our analysis, we did not find a drastic change in our positive affective priming effect (*p*-value = .08, indicating a marginally significant effect). This priming effect was also not modulated by prime RT. In light of these findings, we believe the difference in prime-to-target interval did not underlie the current results.

[2] We also conducted a 3 (prime congruency) x 2 (target valence) repeated measures ANOVA with standardized mean prime RT as a covariate. This analysis showed a marginally significant interaction between prime congruency and target valence, $F(2, 29) = 2.8$, $p = .08$, while the three-way interaction with prime RT was non-significant, $F < 1$.

Additional analyses: Experiments 2A and 2B

In line with our main hypothesis that correctly responding to a conflict stimulus is associated with positive affect, we can also predict a difference between incongruent trials that were correctly responded to versus those that were incorrectly responded to (for a similar reasoning, see Aarts et al., 2012). More precisely, a correct incongruent prime response should engender relatively more positive affect than an erroneous incongruent prime response, because the conflict is resolved in the former but not in the latter trial type. In these additional analyses we therefore tested the influence of prime accuracy on the affective judgment of incongruent primes. To ensure sufficient power (some subjects were excluded due to empty cells because our experiment was not set up to induce sufficient errors), we performed these analyses across Experiments 2A and 2B with experiment as a between-subjects factor and we averaged across SI and RI trials for Experiment 2B. A 2 × 2 × 2 repeated-measures ANOVA was conducted on mean reaction times and error rates, with the within-subjects factors prime response accuracy and target valence, and the between-subjects factor experiment.

Reaction times The RT analysis revealed a main effect of accuracy of the prime response, $F(1, 32) = 97.1$, $p < .001$, $\eta_p^2 = .75$, reflecting a typical post-error slowing effect. Moreover, this effect was more pronounced in Experiment 2B than 2A, $F(1, 32) = 5.4$, $p < .05$, $\eta_p^2 = .14$. All other main or interaction effects were not significant. In particular, the interaction between target valence and accuracy of the flanker task was not significant, $F < 1$.

Error rates A main effect of target valence was found, with more errors on positive words compared to negative words, $F(1, 34) = 11.9$, $p = .001$, $\eta_p^2 = .26$. Importantly, we also found a significant interaction between target valence and accuracy of the prime response, $F(1, 34) = 5.1$, $p < .05$, $\eta_p^2 = .13$, evidencing a positive evaluation of correct responses following incongruent trials, relative to erroneous responses on incongruent trials (see also Fig. 4).

Discussion

These results showed that response accuracy of the primes did indeed influence the affective priming effect, further supporting the conclusion that conflict resolution is associated with positive affect. We detected this effect only in the error rates, which could be due to the smaller number of data points in the RT analysis relative to the main experimental results. These results are in line with a study by Aarts and colleagues

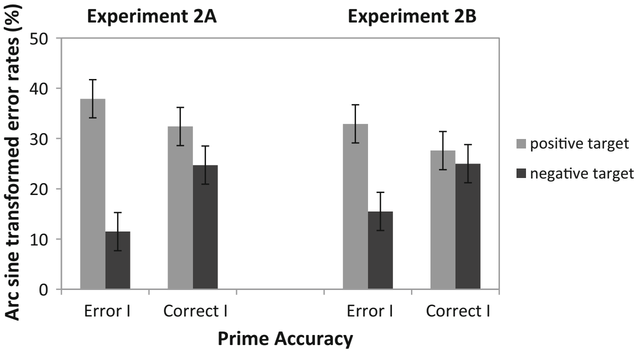

Fig. 4 Mean arc sine transformed error rates for negative and positive word judgments, dependent on the accuracy of the response to incongruent (I) primes, displayed separately for Experiments 2A and 2B. Error bars are based on the mean square error of the interaction term (Loftus & Masson, 1994)

(2012), similarly demonstrating how errors evoke a negative evaluation. However, in order to verify whether this effect is different for (correct and incorrect responses to) congruent primes, we would need to compare the effect of accuracy for incongruent and congruent primes separately. Our experiments were not set up to evoke a high percentage of errors; consequently, too few errors were made on congruent primes. To this end, further studies are needed where the affective valence of task performance for both congruency types can be studied independently.

General discussion

The hypothesis that conflict is aversive (Botvinick, 2007) has spurred a great deal of research. Whereas previous studies suggested that incongruent stimuli are affectively negative (Brouillet et al., 2011; Cannon et al., 2010; Dreisbach & Fischer, 2012; Fritz & Dreisbach, 2013; Lynn, Riddle, & Morsella, 2012; Schouppe et al., 2012; Schouppe et al., 2014; van Steenbergen et al., 2009), our results suggest that conflict resolution results in positive affect. Specifically, in Experiments 2A and 2B we found a positive affective priming effect after correctly *responding* to incongruent primes, relative to correctly *responding* to congruent primes. Our observed positive affective priming effect, induced by responding to incongruent trials, relative to congruent trials, is consistent with the findings of Molapour & Morsella (2011), and could reflect a positive prediction error signal, following the lower outcome expectancy of incongruent than congruent stimuli (Silvetti et al., 2011). More broadly, our findings are also consistent with similar observations and ideas from the animal literature (Alessandri, Darcheville, Delevoye-Turrell, & Zentall, 2008; Klein, Bhatt, & Zentall, 2005; Zentall, 2010), neuroscience (Satterthwaite et al., 2012), cognitive psychology (Molapour & Morsella, 2011), and organizational psychology (i.e. learned industriousness, Eisenberger, 1992), all arguing in favor of the idea that difficult tasks can be perceived as more rewarding than easier tasks.

It is noteworthy that in demonstrating positive affect following conflict resolution, there is also an important alternative interpretation. Specifically, one could interpret our affective priming effect in Experiments 2A and 2B as a *facilitation of negative targets* that were preceded by *congruent primes*, rather than a *facilitation of positive targets* that were preceded by *incongruent primes*. In fact, at first sight, the interaction between prime congruency and target valence seems to manifest as a faster processing of negative targets after congruent compared to incongruent primes. Similarly, when comparing Experiment 1 with Experiment 2A, it seems that the results are mainly driven by the effect of congruent primes. However, it is important to emphasize that priming effects should always be viewed relative against each other. Our exact pattern does not warrant the inference that congruent primes facilitate the evaluation of negative targets (neither does it exclude this interpretation). For example, it is also plausible that a main effect of valence is being countered after incongruent primes, suggesting that the affective priming effect is the result of incongruent primes facilitating the response to positive targets. Furthermore, this main effect of valence could differ across experiments. Therefore, based on our data, we cannot make firm conclusions in favor of either interpretation. Still, we believe that the reverse interaction effect found in Experiments 2A and 2B is an important empirical extension of earlier findings (and our own Experiment 1), showing that when not responded to (and hence when there is no conflict resolution), incongruent primes engender relatively less positive affect than congruent primes. It challenges existing theoretical accounts to explain how this switch in relative valence of congruent and incongruent stimuli could occur. While an interpretation of the interaction effect in terms of heightened negative affect after congruent primes is possible, it is difficult to reconcile this with current theoretical frameworks that focus on conflict and its associated affective value.

Our results are concordant with a very recent study by Fritz and Dreisbach (2014). Similar to our study, Fritz and Dreisbach investigated whether their affective priming effect can be actively counteracted, by studying the time course of this effect. In contrast to our study, however, Fritz and Dreisbach did not allow participants to respond to the prime stimuli, but varied the prime duration and/or prime-target interval between experiments. In line with earlier observations (our Experiment 1; Dreisbach & Fischer, 2012; Fritz & Dreisbach, 2013), they demonstrated that incongruent Stroop trials facilitate negative evaluations relative to congruent Stroop trials when the prime duration was either 200 or 400 ms. Interestingly, however, they further demonstrated how prime duration, but not prime-target interval, can modulate this effect to the extent that the affective priming effect exclusively reversed when Stroop stimuli were presented for 800 ms. Because the effect did not reverse in conditions with prime durations of 200 or 400 ms followed by prime-target intervals of 600 or 400 ms, respectively, Fritz and Dreisbach (2014) concluded that the Stroop stimuli evoked a resource-consuming active counter-regulation process, but only when prime presentation was sufficiently long (i.e., 800 ms).

On the basis of our framework we can offer a more detailed explanation by proposing that participants covertly resolved the cognitive conflict induced by the prime stimuli in their experiment, thereby driving this active counter-regulation process. This is supported by two observations from our present dataset. First, we demonstrated in two experiments how prime duration (by means of both median split analyses and covariate analyses) did not influence the affective priming effect. Instead, merely correctly responding to the stimuli was sufficient for demonstrating that incongruent primes engendered relatively more positive affect compared to congruent primes. Second, if our affective priming effect would depend on prime duration, rather than task performance, it should not be affected by response accuracy in the prime task. Importantly, additional analyses contradict this, showing a difference in affective priming between correct versus incorrect responses to incongruent trials. These findings stress the role of performance monitoring (rather than mere prime-target intervals) in bringing about our affective priming effect.

Experiment 2B served as a replication experiment in which we could extend our findings to another type of conflict (Stroop instead of flanker), and moreover differentiate between stimulus and response conflict. The results showed that positive affective priming can be observed for the resolution of both stimulus and response incongruent (Stroop) stimuli. However, while our affective priming results did not differentiate between both trial types, one could have predicted a more positive affect on RI compared to SI trials. Under the rationale that more conflict is present on RI trials (e.g., Van Veen & Carter, 2005), it can be argued that a larger degree of conflict resolution is needed on those trials, resulting in more positive affect. While acknowledging this possibility, recent electrophysiological studies demonstrated that ACC activity, induced by SI or RI trials, does not always differentiate between the two trial types (Nigbur, Cohen, Ridderinkhof, & Stürmer, 2012; Wendt, Heldmann, Münte, & Kluwe, 2007). Therefore, in line with the RVPM model of ACC, our findings are more consistent with these studies, showing that the conflict-induced positive affective priming effect should not depend on conflict type (stimulus or response conflict). Moreover, the presence of affective priming effects demonstrates an automatic evaluation and categorization of the primes (congruency conditions). Keeping this in mind, it is likely that participants tracked the salient distinction between congruent and incongruent trials, classifying them into easy and difficult categories, while overlooking the more subtle difference in difficulty between SI and RI trials.

Our results have important implications for theories of cognitive control. Until now, these theories have mainly focused on the aversive nature of cognitive conflict. For example, it has been argued that this negative valence may drive adaptations to conflict (Botvinick, 2007). Consistently, van Steenbergen et al. (2009) found that conflict adaptation disappears in a state of positive mood (see also Braem, King, Korb, Krebs, Notebaert, & Egner, 2013; Kuhbandner & Zehetleitner, 2011; Schuch & Koch, 2014). They argued that a positive mood counteracts the negative valence of conflict and thus eliminates adaptation after conflict. These findings are in line with other theories postulating that positive mood increases task distractibility (Dreisbach & Goschke, 2004; Dreisbach, 2006) and could suggest that cognitive control is mainly driven by aversive task demands.

However, our findings shed a new light on this issue. In contrast to Botvinick (2007) and van Steenbergen et al. (2009), we suggest that conflict adaptation might as well be caused by the intrinsic positive evaluation that occurs after correctly responding to difficult stimuli (as also suggested by Braem, Verguts, Roggeman, & Notebaert, 2012). The rewarding value of resolving an incongruent stimulus may motivate a person to enhance the task focus that drove him/her to that response. Computationally, this would mean that task-relevant associations are strengthened following (intrinsic) reward experience (for instance, as implemented in the adaptation by binding model, Verguts & Notebaert, 2009). It would imply that conflict resolution, rather than conflict itself, triggers adaptations. This hypothesis does not exclude that cognitive adaptations are driven by the aversiveness of conflict. However, we suggest that this may occur more indirectly than originally thought; the intrinsic positive evaluation triggered by resolving the (aversive) cognitive conflict can be what motivates us in adapting our strategy. This idea is in line with the observation that cognitive conflict and errors trigger different adaptations (Notebaert & Verguts, 2011; Stürmer, Nigbur, Schacht, & Sommer, 2011; Van der Borght, Braem, & Notebaert, 2014) and the observation that conflict adaptation is increased following performance-related reward, and disappears after reward omission (Braem et al., 2012). Note, however, that these studies did not control for alternative interpretations of conflict adaptation in terms of contingency learning and feature integration (Hommel, 1998; Mayr et al., 2003; Mordkoff, 2012; Schmidt & De Houwer, 2011; Schmidt, 2013). Although recent studies that excluded such episodic learning effects by design still found reliable conflict adaptation effects (Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014a, b; Kim & Cho, 2014; Schmidt & Weissman, 2014), the impact of motivational or affective variables on such conflict adaptation studies remains to be investigated.

In summary, we demonstrated that conflict resolution, relative to correctly responding to congruent trials, can have a positive connotation. These findings have important implications for the current theorizing on the role of conflict in cognitive control and suggest that theories should include this potential rewarding role in explaining 'cognitive' (trial-to-trial) adaptations.

Author note The research reported in this article was supported by grant no. 3F011209 and G.0098.09N of Research Foundation - Flanders.

Author contributions N. Schouppe, S. Braem, and W. Notebaert developed the study concept. All authors contributed to the study design. N. Schouppe and S. Braem performed the data collection and data analysis. N. Schouppe and S. Braem interpreted the data and drafted the manuscript under supervision of J. De Houwer, T. Verguts, R. Ridderinkhof, and W. Notebaert. All authors provided critical revisions and approved the final version of the manuscript for submission.

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