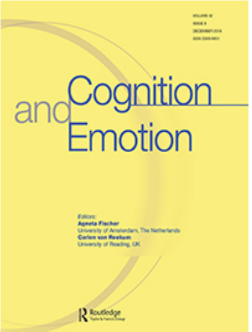

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Conflict-driven adaptive control is enhanced by integral negative emotion on a short time scale*

Qian Yang and Gilles Pourtois

Cognitive & Affective Psychophysiology Laboratory, Department of Experimental Clinical and Health Psychology, Ghent University, Ghent, Belgium

ABSTRACT

Negative emotion influences cognitive control, and more specifically conflict adaptation. However, discrepant results have often been reported in the literature. In this study, we broke down negative emotion into integral and incidental components using a modern motivation-based framework, and assessed whether the former could change conflict adaptation. In the first experiment, we manipulated the duration of the inter-trial-interval (ITI) to assess the actual time-scale of this effect. Integral negative emotion was induced by using loss-related feedback contingent on task performance, and measured at the subjective and physiological levels. Results showed that conflict-driven adaptive control was enhanced when integral negative emotion was elicited, compared to a control condition without changes in defensive motivation. Importantly, this effect was only found when a short, as opposed to long ITI was used, suggesting that it had a short time scale. In the second experiment, we controlled for effects of feature repetition and contingency learning, and replicated an enhanced conflict adaptation effect when integral negative emotion was elicited and a short ITI was used. We interpret these new results against a standard cognitive control framework assuming that integral negative emotion amplifies specific control signals transiently, and in turn enhances conflict adaptation.

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Conflict; adaptive control; integral negative emotion; feedback; motivation

Flexible goal-directed behaviour depends on adaptive monitoring systems meant to detect mismatches or conflicts, supplemented with adjustment/corrective systems to resolve them (Holroyd & Coles, 2002; Verguts & Notebaert, 2009). Converging evidence from cognitive psychology and cognitive neuroscience suggests that adaptive control processes could be triggered by conflict (Shackman et al., 2011; Shenhav, Botvinick, & Cohen, 2013). Within the dominant conflict monitoring theory, the online and trial-by-trial task adjustment is usually achieved by increasing cognitive control upon conflict detection with effects visible on the subsequent trial, as exemplified by conflict adaptation (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Conflict adaptation translates an improved conflict resolution effect following incongruent trials (high conflict situation), which is thought to result from dedicated conflict-driven adaptive control mechanisms (Clayson & Larson, 2011).

Interestingly, recently, the affective and motivational consequences of conflict detection and resolution have been better scrutinised in the existing literature, with the emerging finding that conflict is actually negative, or even aversive to some extent (Dreisbach & Fischer, 2012b; Fritz & Dreisbach, 2013; Schouppe et al., 2015), suggesting that trial by trial changes in cognitive control might very well result from changes in negative emotion (or defensive motivation) rather than conflict per se. In this framework, several studies have explored the relationship between negative emotion and conflict-driven adaptive control (Dreisbach & Fischer, 2012a; Dreisbach & Fischer, 2015; Schuch & Koch, 2015; Van Steenbergen,

CONTACT Gilles Pourtois gilles.pourtois@ugent.be
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Band, & Hommel, 2009, 2010, 2012). However, somewhat inconsistent results have been reported in this literature (see Table 1), with sometimes facilitatory, deleterious, or no clear effect of negative emotion on cognitive control (Braem, Duthoo, Notebaert, & Zalla, 2013; Kanske, 2012; Stürmer, Nigbur, Schacht, & Sommer, 2011). A closer look at these studies (see Table 1) suggests that the way negative emotion was manipulated (and/or operationalised, as well as measured) differed substantially across them. Either "sustained negative emotion" by altering the current mood state of the participant (Kuhbandner & Zehetleitner, 2011; Schuch & Koch, 2015; Schuch, Zweerings, Hirsch, & Koch, 2017; Van Steenbergen et al., 2010), or alternatively "transient negative emotion" by using affective/evocative stimuli shown in between trials (such as emotional images or feedback) was actually used in these studies (Braem et al., 2013; Fritz, Fischer, & Dreisbach, 2015; Padmala, Bauer, & Pessoa, 2011; Stürmer et al., 2011; Van Steenbergen et al., 2009, 2010, 2012). Accordingly, this dimension (i.e. sustained vs. transient negative affect) might potentially explain this discrepancy since sustained negative emotion appears to ease cognitive control while transient negative emotion could perhaps impede its implementation (see Table 1).

However, even when this specific dimension is considered, it appears rather difficult to draw clear conclusions regarding the direction of the change in cognitive control triggered by negative emotion. In particular, for transient negative emotion, discrepant results have been reported in the past. One factor accounting for these mixed results may be whether transient negative emotion was performance-contingent or not (Braem et al., 2013; Stürmer et al., 2011; Van Steenbergen et al., 2009, 2012). Specifically, performance-non-contingent negative feedback increased conflict adaptation (Van Steenbergen et al., 2009, 2012), whereas this effect was not found when negative feedback was performance-contingent (Braem et al., 2013; Stürmer et al., 2011). Noteworthy, this link between negative emotion and conflict adaptation (depending on event contingency) was restricted to situations where negative information was signalled by evaluative feedback specifically, however. If non-performance-contingent negative emotion was not manipulated through feedback, but using other means (e.g. emotional images or disfluency of stimuli), conflict adaptation was usually eliminated, rather than increased (Fritz et al., 2015; Padmala et al., 2011). Therefore, non-performance-contingent negative emotion does not unconditionally trigger enhanced conflict control. Sometimes it can even counteract the normal facilitatory effect triggered by negative emotion associated with conflict processing per se. Hence, the influence exerted by transient negative emotion on conflict adaptation appears to be malleable and context-dependent. Interestingly, if the negativity arising from conflict processing could be integrated (or reinforced) "directly" and rapidly with an external negative stimulus or signal (even if it is not performance contingent), then a systematic facilitation on control adjustment could probably be observed, as a review across the existing studies indirectly suggests (see Table 1). Yet, it remains currently unclear which source and type of external negative emotion or signal could foster this integration with the putative aversiveness associated with conflict processing, and in turn influence conflict adaptation. In this study (see e.g. Experiment 2), we addressed this question.

On the other hand, the rather versatile influences of transient negative emotion on conflict-driven adaptive control may suggest that their interplay is actually more complex than initially thought, although they share common variance as well as neurobiological ground (Melcher, Born, & Gruber, 2011; Stürmer et al., 2011). In some cases, negative emotion (negative images or disfluency of stimuli) might presumably consume important cognitive resources "centrally" that should be used otherwise to meet task demands (creating an extra load somehow), thereby resulting in a deleterious effect on task performance (Pessoa, 2009). Alternatively, in other situations, negative emotion (feedback) might act as a valuable motivational signal, triggering improved control and hence better task performance (on the subsequent trial) as a result (Kanske, 2012; Pessoa, 2009). Further, in a recent study, it has been shown that the experience of conflict (at the subjective level) is necessary for triggering systematic adjustments in conflict-driven adaptive control (Desender, Van Opstal, & Van den Bussche, 2014; but see Foerster, Pfister, Reuss, & Kunde, 2017). Experiencing conflict at the subjective level could be associated with a specific category of negative emotion, namely "integral negative emotion" (see Inzlicht & Legault, 2014; Inzlicht, Bartholow, & Hirsh, 2015), which alerts the organism for the need to exert additional control or effort to overcome this challenge.

More specifically, integral negative emotion corresponds to specific motivational effects closely related to the task itself. For example, conflict detection and

Table 1. Overview of existing studies on conflict adaptation and negative emotion.

Study	Manipulation of negative emotion	Effect of conflict adaptation	Classification	Response-to-stimulus interval, RSI
Sustained negative emotion				
Schuch et al. (2017)	Negative mood was induced by bogus intelligence test	CAE increased	Long-term negative incidental emotion	EX1:Correct response: 1000 ms Incorrect response: 2000 ms EX2:Correct response: 500 ms Incorrect response: 1500 ms
Schuch and Koch (2015)	Negative mood was induced by film clips	CAE increased	Long-term negative incidental emotion	Correct response: 1000 ms Incorrect response:2000 ms
Kuhbandner and Zehetleitner (2011)	Negative mood was induced by the combination of music with imagination	CAE increased	Long-term negative incidental emotion	1000 ms
Van Steenbergen et al. (2010)	Negative mood was induced by the combination of music with imagination	CAE increased	Long-term negative incidental emotion	Randomly varying duration of 800, 1000, or 1100 ms
Van Steenbergen et al. (2010)	Negative affect was manipulated by depressive symptoms by using acute tryptophan depletion (ATD)	CAE increased	Long-term negative incidental emotion	Fixed: 2250 ms Varied: 2250–5500 ms
Transient negative emotion				
Dreisbach, Reindl and Fischer (2016)	Negative emotion was manipulated by the position of stimulus presentation (lower position is more negative)	Negative emotion impaired task performance (decreased reaction time)	Short-term incidental negative emotion	Correct response: 1250 ms Incorrect response: 1750 ms
Dignath, Janczyk, and Eder (2017)	Negative emotion was manipulated by negative pictures	No significant change (compared with positive emotion)	Short-term incidental negative emotion	1100 ms
Fritz et al. (2015)	Negative emotion was manipulated by disfluency of stimuli	CAE decreased	Short-term incidental negative emotion	Correct response: 1250 ms Incorrect response: 2250 ms
Hengstler, Holland, van Steenbergen, and van Knippenberg (2014)	Negative emotion was manipulated by avoidance (arm extension)	CAE increased	Short-term incidental negative emotion	1000 ms
Braem et al. (2013)	Negative feedback were contingent upon task performance	CAE after negative feedback was numerically larger than neutral feedback (but did not reach significance)	Short-term integral negative emotion	2000 ms
Van Steenbergen et al. (2012, 2009)	Negative feedback were non-contingent upon task performance	CAE increased	Short-term incidental negative emotion	800 ms
Stürmer et al. (2011)	EX1: Negative feedback were non-contingent upon task performance; EX2: Negative feedback were contingent upon task performance	EX1: no effect of random negative (positive) feedback on CAE; EX2: no effect of task-contingent negative feedback	EX1: Short-term incidental negative emotion EX2: Short-term integral negative emotion	1500 ms

Note: In our study, the RSI was 2400 ms for Experiment 1A (long ITI) and 1900 ms for Experiments 1B-2 (short ITI).

error making occurring when participants perform standard interference tasks, since being both aversive, can be seen as two processes that contribute to the elicitation of integral negative emotion. By comparison, incidental negative emotion is not directly bound to the task, but can be regarded as a byproduct of it to some degree, such as a specific affective state created by the context or environment, resembling in turn mood or indirect (emotion) regulation effects (Hobson, Saunders, Al-Khindi, & Inzlicht, 2014; Västfjäll et al., 2016). Notably, even though these two classes of effects (integral vs. incidental negative emotion) are partly dissociable, usually they overlap and probably interact with one another in a rather non-transparent way, and thereby, they could generate either facilitation or interference (or no effect if they happen to cancel each other out) during adaptive control depending on their specific combination and configuration at a specific time. Notwithstanding these caveats, effects of negative emotion on cognitive control could probably be better explained (and discrepant findings in the literature perhaps reconciled) by using this alternative motivational account (Inzlicht et al., 2015; see also Table 1).

In light of these properties and the motivation-based framework outlined here above, it appears obvious that the dichotomy between integral vs. incidental negative emotion also shares many similarities with the distinction between transient and sustained negative emotion. When being sustained, such as negative mood for example, negative emotion seems to improve conflict adaptation consistently (Table 1). By comparison, and as briefly reviewed here above, when being primarily transient, effects of negative emotion on conflict adaptation are rather mixed. Moreover, the "salience" of the conflict signal might lose its propensity to enhance control when negative emotion is elicited, although the control functions remain unaffected by this change (Dreisbach et al., 2016). In this study, we sought to explore possible modulatory effects of integral negative emotion on conflict adaptation, when it was conceived as a phasic event primarily, as operationalised as performance feedback contingent on task performance and being associated with punishment-related motivation.

Apart from affective variables that account for some of the variance in adaptive control at the behavioural level, there are also of course structural factors related to the stimulus and task itself that eventually determine its strength and efficiency. The duration of the inter-trial interval (ITI) undoubtedly belongs to them, given that control mode driven by conflict adaptation is usually characterised by fast-changing adjustments on a trial-by-trial basis (Bugg & Chanani, 2011). When the focus is on trial by trial fluctuations in conflict monitoring and resolution, obviously, the length of the gap included between successive trials is utmost important, and causally influences online task adjustments. During the ITI, proactive processing geared toward effective control of performance is at stake (Egner, Ely, & Grinband, 2010). Consistent with this idea, previous studies have found that conflict adaptation was larger at short compared to long ITI (Egner, Etkin, Gale, & Hirsch, 2008; Wühr & Ansorge, 2005). At short ITI, the monitoring process initiated by conflict detection during the previous trial has presumably not completely faded out yet, such that the current trial is subject to online adjustments in terms of (control) processes (activated during the previous trial). By comparison, if the length of the ITI is extended substantially, no such lingering control effect from the previous to the current trial could take place, cancelling in turn conflict adaptation. However, if and how integral negative emotion impinges on this effect (created by the ITI) remains unclear and has, to the best of our knowledge, been investigated only indirectly in a limited number of studies so far (see Table 1). Using a priming methodology, Fritz and Dreisbach (2015) previously found that conflict facilitated negative emotion when the ITI was short (200–400 ms), but not when it was increased up to 800 ms (see also Fritz & Dreisbach, 2013, 2015). Arguably, variations in the duration of the ITI across studies might also account for some of the divergent results reported regarding the modulatory role of negative emotion on cognitive control, or the lack thereof (see Table 1).

The main objective of the current study was to explore effects of negative emotion on conflict-driven adaptive control using a speeded Eriksen flanker task (Experiments 1A and 1B), when negative emotion was directly and selectively operationalised as an integral component of the task. More specifically, we used and compared (using different blocks) feedback contingent on task performance that was either neutral or motivationally significant, since being punishment related. According to the framework put forward by Inzlicht et al. (2015), this latter situation could very well facilitate conflict adaptation as the negativity associated with conflict processing is transiently enhanced or boosted by the presentation of the subsequent and contingent feedback carrying an enhanced negative motivational value. In addition, we surmised that such an effect should be evidenced when using a short, as opposed to long ITI (Egner et al., 2010). To this aim, in Experiments 1A and 1B, we used an Eriksen flanker task and a factorial design with ITI and integral negative emotion as between-subjects and within-subject variables, respectively.

Experiments 1A and 1B

Method

Participants

Thirty-two participants took part in Experiment 1A and thirty different in Experiment 1B. Three participants were excluded from the analyses in Experiment 1A: one did not finish the experiment and two others had a mean accuracy lower than 60%. Two participants in Experiment 1B were excluded from the analyses because of a mean accuracy lower than 60%. These criteria resulted in a final sample of 29 in Experiment 1A (mean age = 22.9 years, SD = 2.6, 6 males), and of 28 participants in Experiment 1B (mean = 22.6 years, SD = 2.7, 7 males) available for subsequent analyses. As the amount of money participants lost during the experiment was over 3 Euro (average: 4.14 Euro), they were all finally compensated 10 Euro (see procedure here below). All participants had normal or corrected-to-normal vision, and no history of psychiatric or neurological disorders.

Stimuli and task

Participants were seated in front of a computer monitor and performed a speeded Eriksen flanker task (Eriksen & Eriksen, 1974). Each trial started with a fixation cross that was used as ITI. The length of the ITI was manipulated across the two experiments, with a mean ITI of 1000 ms (range: 900–1100 ms) in Experiment 1A and of 500 ms (range: 400–600 ms) in Experiment 1B. After the fixation cross, a row of five arrows was presented in the middle of screen for 1000 ms or until a response was given, followed by a black screen shown for 700 ms, before a performance-contingent feedback was presented centrally for 700 ms (Figure 1A). Either a positive feedback signalled by a green dot was provided if the response was correct and fast enough (i.e. falling below the response deadline corresponding to an arbitrary time limit), or a negative feedback signalled by a red dot was provided if the response was incorrect or too slow (i.e. above this time limit). With regard to the time limit, we used an algorithm used and validated previously that enforces fast responding (Aarts & Pourtois, 2010; Vocat, Pourtois, & Vuilleumier, 2008; see details in supplementary materials), and ensures a balanced proportion of positive and negative feedback on average, without yielding excessive frustration. Unknown to participants, the reaction time (RT) cutoff was updated on a trial-by-trial basis to deal with unwanted fatigue or habituation effects throughout the experimental session.

Procedure

Before the start of the experiment, participants gave informed consent and performed a practice phase that consisted of two blocks comprising 17 trials each. The experimental session consisted of 6 blocks of 121 trials each. There were two different block types (resulting in 3 blocks per condition): negative vs. neutral block. Two specific orders were used: P-N-N-P-P-N or N-P-P-N-N-P, with P referring to punishment (negative) block, and N to neutral block. The procedure was the same for the two block types, with the notable exception that negative blocks included monetary losses in case of negative feedback encountered (i.e. errors or slow RTs). More specifically, participants were informed that unlike neutral blocks where incorrect or slow responses had no consequences, each negative feedback received during the negative blocks would be converted to a 2 cent monetary loss. They were also told that positive feedback would not/never be rewarded (with monetary gains), hence punishment motivation, but not reward motivation, was elicited during these blocks. At the end of each negative block ($n = 3$), a general feedback was provided indicating “the number of trials associated with too slow RTs”, “the number of trials associated with response errors”, and thereby “the total amount of money lost”. For neutral blocks, no general feedback was provided at the end of each of them. At the start of each block, participants were encouraged to make accurate and fast responses. For each and every trial, participants were asked to perform a two-alternative forced choice task regarding the direction of the central arrowhead (either left or right) flanked by four compatible or incompatible arrowheads, using two predefined keys of a response box, and their right (dominant) hand (see Figure 1A). Prior to the start of the first block, they were informed that they could get a maximum payoff of 13 Euro in case they would perform flawlessly (i.e. not receiving any negative feedback during the negative blocks). Hence, they were informed that every negative feedback received during the negative blocks would reduce this total amount by 2 cent. In between blocks, self-paced breaks were allowed. Stimuli were shown in a pseudo-random order within each block to lead to the same number on average of congruent-Congruent (cC), congruent-Incongruent (cI), incongruent-Congruent (iC), incongruent-Incongruent (iI) trials used to compute offline conflict adaptation. Stimuli presentation and data recording were controlled using E-Prime (Version 2.0; Psychology Software Tools Inc., Sharpsburg, PA).

Questionnaires

Positive and negative affect schedule. A Dutch version of the Positive and Negative Affect Schedule (PANAS) was used to measure changes in negative

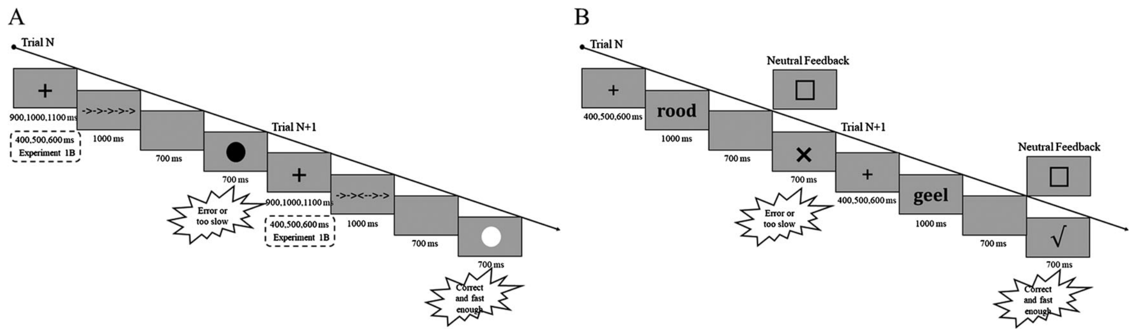

Figure 1. Experimental procedure. A. Experiments 1A and 1B. Each trial started with a fixation cross (that lasted on average either 1000 ms – Experiment 1A, or 500 ms – Experiment 1B), followed by the flanker stimuli. A blank screen ensued, before the task contingent feedback was presented. B. Experiment 2. Each trial started with a fixation cross (that lasted on average 500 ms), followed by the Stroop stimulus. A blank screen ensued, before the task contingent feedback was presented (being either informative or neutral). The figure shows an example of a cI trial for the two tasks.

emotion between the two different block types and thus served as main manipulation check. The scale consists of 20 words that describe different feelings and emotions (10– items for negative affect and 10– items for positive affect). In order to measure participants' negative emotion in each separate block, participants were asked to report their subjective feelings at the end of each of them (hence, 6 times in total), by rating the items on a 5-point scale ranging from 1 – *Very slightly* or *not at all* to 5 – *Extremely*. In addition, the order of these 20 items was alternated across these 6 measurement points (one after every block) to reduce the use of any predefined response strategy, or the anticipation of specific emotional words. At the end of the experiment, we also administered the Dutch version of the Penn State Worry Questionnaire (PSWQ; Watson, Clark, & Tellegen, 1988) to perform exploratory analyses between this specific trait, negative emotion (PANAS) and conflict adaptation (see supplementary materials).

Data analyses

Manipulation check. The values of negative affect and positive affect were obtained from the sum of scores on negative and on positive items, respectively, for long ITI and short ITI conditions separately. The resulting PANAS values were then submitted to a mixed-model ANOVA with ITI (long, short) as a between-subjects factor, Affect (negative, positive) and Block Type (negative, neutral) as within-subject factors.

Analyses of behavioural data based on conflict adaptation. First, for each subject separately, the first trial of each block, any subsequent error trials, post-error trials and trials where RTs were larger than 3 standard deviations (SDs) above or below the mean RT were excluded from further analyses. Next, mean RT was computed for each condition separately. Mean RTs (and error rates) were submitted to a mixed-model analysis of variance (ANOVA) with ITI (long, short) as a between-subjects factor, Emotion (negative, neutral), Previous Congruency (congruent, incongruent), and Current Congruency (congruent, incongruent) as within-subject factors. A standard alpha level of .05 was used for all statistical tests.

Results

Manipulation check

The ANOVA showed a significant effect of Block Type, with higher subjective ratings in negative compared with neutral blocks, $F(1, 55) = 9.035$, $p = .004$, $\eta_p^2 = 0.141$. Importantly, the interaction between Affect and Block type was also significant, $F(1, 55) = 8.798$, $p = .004$, $\eta_p^2 = 0.138$. Follow-up statistical comparisons confirmed that the scores for negative affect were significantly higher in negative than neutral blocks, $t(56) = 4.008$, $p < .003$, $d = 0.53$, 95% CI [0.95, 2.84], while they did not differ significantly between the two Block types for positive affect, $t(56) = 0.369$, $p = .713$, $d = 0.05$ (see Figure 2A).

Behavioural results

The ANOVA performed on mean RTs for correct responses showed that the Previous Congruency was marginally significant, $F(1, 55) = 3.49$, $p = .067$, $\eta_p^2 = 0.06$, while the Current Congruency was highly significant, $F(1, 55) = 371.9$, $p < .001$, $\eta_p^2 = 0.871$.

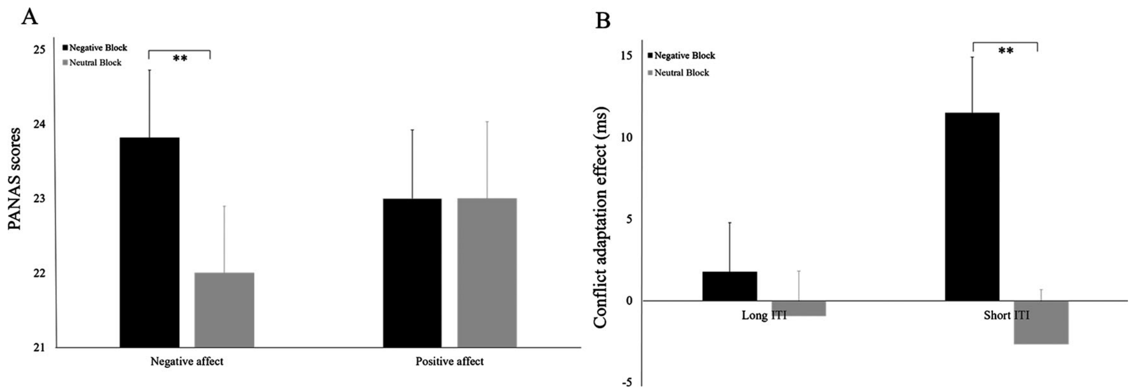

Figure 2. Results of Experiments 1A and 1B. A. Subjective negative affect was higher in negative than in neutral blocks, while subjective positive affect did not differ between these two conditions. B. The CAE was absent and not significantly different between negative and neutral blocks when the ITI was long (Experiment 1A). By comparison, the CAE was significant higher in negative compared to neutral blocks when the ITI was short (Experiment 1B) (see Supplementary Materials for statistical analyses run on these CAE scores). The error bar represents the standard error (SE). $^{**}p < 0.01$.

Importantly, the three-way interaction between Emotion, Previous Congruency and Current Congruency was significant, $F(1, 55) = 7.886$, $p = .007$, $\eta_p^2 = 0.125$, indicating that conflict adaptation was modulated by Emotion (Figure 3). The four-way interaction was marginally significant, $F(1, 55) = 3.6$, $p = .062$, $\eta_p^2 = 0.06$.

To explore these complex interaction effects further and test our prediction, two separate three-way ANOVAs with Emotion (negative, neutral), Previous Congruency (congruent, incongruent), and Current Congruency (congruent, incongruent) as within-subject factors were run, for each experiment (and thus ITI) separately. For Experiment 1A (long ITI), the Previous Congruency was significant, $F(1, 28) = 9.694$, $p = .004$, $\eta_p^2 = 0.257$, as well as the Current Congruency, $F(1, 28) = 245.55$, $p < .001$, $\eta_p^2 = 0.898$, but the three-way interaction was not, $F(1, 28) = 0.421$, $p = .522$, $\eta_p^2 = 0.015$ (see Figure 3A). For Experiment 1B (short ITI), the Current Congruency was significant, $F(1, 27) = 143.447$, $p < .001$, $\eta_p^2 = 0.842$, as well as the three-way interaction, $F(1, 27) = 10.767$, $p = .003$, $\eta_p^2 = 0.29$ (see Figure 3B), indicating that conflict adaptation was different in negative compared to neutral blocks. To break down this latter three-way interaction, we ran two separate ANOVAs with Previous Congruency (congruent, incongruent) and Current Congruency (congruent, incongruent) as with-subject factors, for each

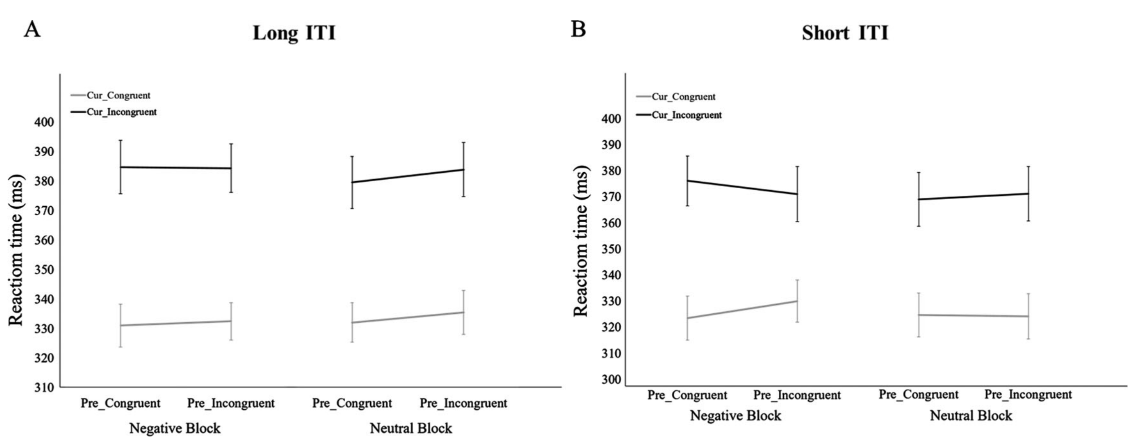

Figure 3. Results of Experiments 1A and 1B. Behavioural results (RT speed) showing that both ITI (long vs. short) and Block type (negative/punishment-related vs. neutral) jointly contributed to the CAE. A. No reliable CAE was observed when the ITI was long. B. A significant CAE was observed when the ITI was short, and negative emotion (i.e. punishment-based motivation) was elicited. The error bar represents the standard error (SE).

Block type separately. For negative blocks, the ANOVA showed a significant main effect of Current Congruency, $F(1, 27) = 116.044$, $p < .001$, $\eta_p^2 = 0.811$ and a significant interaction effect between these two factors, $F(1, 27) = 11.55$, $p = .002$, $\eta_p^2 = 0.3$. This latter interaction indicated faster RTs in cC trials (323 ms) than in iC trials (330 ms), $t(27) = 4.262$, $p < .001$, $d = 0.81$, 95% CI [3.35, 9.58], while iI trials (371 ms) were also performed faster than in cI trials (376 ms), even though this latter difference did not reach significance, $t(27) = 1.607$, $p = .12$, $d = 0.30$, 95% CI [−1.40, 11.49]. By comparison, for neutral blocks, only the main effect of Current Congruency was significant, $F(1, 27) = 144.2$, $p < .001$, $\eta_p^2 = 0.842$, whereas the interaction effect was not, $F(1, 27) = 0.627$, $p = .435$, $\eta_p^2 = 0.023$, (see Figure 3B).

Error rates. The ANOVA performed on the error rates revealed a significant interaction effect between Previous Congruency and Current Congruency, $F(1, 55) = 19.609$, $p < .001$, $\eta_p^2 = 0.263$, without significant modulation by Emotion and ITI, however (all Fs$(1, 55) \leq 0.361$, $ps \geq .551$, η_p^2 s ≤ 0.007).

Discussion

Manipulation checks based on subjective ratings (PANAS) confirmed that integral negative emotion was reliably elicited; it was also associated with the activation of the defensive motivational system (Lang & Bradley, 2010), as evidenced based on the results obtained for the peripheral physiology (see supplementary materials). Importantly, and in agreement with our main prediction, the behavioural results showed that integral negative emotion increased cognitive control, yet with clear boundaries found in the expression of this modulatory effect: it improved conflict-driven adaptive control at short ITI (evidenced by increased conflict adaptation in negative compared to neutral blocks); whereas at long ITI, conflict-driven adaptive control was not significantly modulated by it.

Experiment 2

Because the Eriksen flanker task we used in Experiments 1A and 1B did not allow to rule out the contribution of feature repetition and/or contingency learning to the CAE (Mayr, Awh, & Laurey, 2003; Schmidt, 2013) (although control analyses showed that it was not simply explained by repetitions; see supplementary materials), we used a color-word Stroop task in this experiment to control for these potential confounds more directly, and eventually assessed if integral negative emotion could increase conflict adaptation, using a within-subject experimental design. Further, we sought to break down integral negative emotion into two main components to assess which of them was actually responsible for the enhanced conflict adaptation with this specific motivational variable. Using a factorial design, we compared effects of evaluative feedback vs. punishment motivation per se. As a result, Experiment 2 included four main conditions differing as a function of the type and amount of integral negative emotion elicited each time. A first condition included informative (i.e. evaluative) and punishment-related feedback, similarly to negative blocks used in Experiments 1A and 1B. Another condition included informative feedback, yet without motivational significance as it was not associated with monetary loss (for slow responses or errors), in keeping with the neutral blocks used in Experiments 1A and 1B. A third condition omitted the informative feedback delivered on a trial by trial basis (i.e. feedback was provided on a trial by trial basis, but always with a neutral content) but included monetary loss for incorrect or slow responses, however. A last condition, used as control baseline, also lacked informative feedback, and punishment motivation was removed. We predicted that conflict adaptation should increase with integral negative emotion; that is, when informative feedback is delivered on a trial by trial basis and has a distinctive loss-related motivational value (Inzlicht et al., 2015).

Method

Participants

Thirty-three participants (all native Dutch speakers) took part in Experiment 2. None of them participated either to Experiments 1A or 1B. Four participants were excluded from the analyses because of a mean accuracy lower than 60%. This criterion resulted in a final sample of 29 participants (mean age = 22.7 years, SD = 2.0, 11 males) available for subsequent analyses. As the amount of money participants lost during the experiment ranged between 3.72 and 4.92 Euro (average: 4.28 Euro), they were finally compensated 10–11 Euro (see procedure here below). All participants had normal or corrected-to-normal vision, and no history of psychiatric or neurological disorders.

Stimuli and task

Participants were seated in front of a computer monitor and performed a speeded Stroop task (Weissman, Jiang, & Egner, 2014). For each trial, a Stroop stimulus appeared at the centre of the computer screen until the participant responded. Participants were instructed to identify the colour in which the word appeared as fast and accurately as possible by using four predefined keys of a response box, corresponding to the four colours used (red, blue, green, yellow). To do so, they used their left middle finger to respond to red colour, left index finger to blue colour, right index finger to green colour, and right middle finger to yellow color.

The Stroop stimuli consisted of four words (in Dutch) ("rood"/red, "blauw"/blue, "groen"/green, or "geel"/yellow; font size, 30 points) presented in one out of four possible colours (red, RGB: 255, 0, 0; blue, RGB: 0, 176, 240; green, RGB: 0, 255, 0; yellow, RGB: 255, 255, 0). For a given participant, each word was presented in only two of the possible four colours however (see below). To rule out contingency learning, a four-alternative forced choice (4-AFC) task was used (Schmidt & Weissman, 2014; Weissman et al., 2014), where two pairs of S-R were created arbitrarily to balance congruent and incongruent trials. Each pair consisted of two words and two colours such that incongruent trials were created for the (incompatible) word-color association within each pair, but not across pairs. According to this rule, 8 stimuli types were created in total (instead of 16 if all combinations were constructed), corresponding to 4 stimuli for congruent trials and 4 stimuli for incongruent trials. Each word was presented equally often in the congruent and incongruent colour in each block within each mapping (Mordkoff, 2012). Since each block included 81 trials, each of the 8 stimuli was presented 10 times. To rule out feature repetitions across successive trials, the stimuli were systematically alternated across them to ensure that there was no stimulus (or response) repetition for both goal-relevant (colour) and goal-irrelevant (meaning) dimensions.

Procedure

Stimulus presentation and duration were identical to those used in Experiment 1B (short ITI version) where conflict adaptation was found to be enhanced with negative emotion (see results here above). Specifically, each trial started with a fixation cross that was used as ITI, with a mean ITI of 500 ms (range: 400–600 ms). After the fixation cross, the Stroop stimulus was presented in the middle of the screen for 1000 ms or until a response was given, followed by a black screen shown for 700 ms, before either an informative or a neutral feedback was presented centrally for 700 ms (Figure 1B). For the informative feedback, either a positive feedback signalled by a black tick mark was provided if the response was correct and fast enough (i.e. falling below the response deadline corresponding to an arbitrary the time limit), or a negative feedback signalled by a black cross was provided if the response was incorrect or too slow (i.e. above this time limit). The neutral feedback signalled by a black square indicated a response had been made, without specific information provided about task performance and accuracy, however. The general settings of the response deadline (adapted on a trial by trial basis, see supplementary materials) were identical to Experiments 1A and 1B, but with a different general limit used (i.e. 700 ms, whereas it was 495 ms in Experiments 1A and 1B), due to the use of a more complex task here (Stroop) leading to longer RTs on average than the Flanker task used in Experiments 1A and 1B (see Figure 1B).

Before the start of the experiment, participants gave informed consent and performed a practice phase that consisted of four blocks comprising 13 trials each. The experimental session consisted of 12 blocks of 81 trials each, which corresponded to four different conditions: Punishment-informative Feedback (condition A), Punishment-neutral Feedback (condition B), no Punishment-informative Feedback (condition C), and no Punishment-neutral Feedback (condition D). Each condition comprised 3 blocks that were shown successively ("triplet"). Condition A, where informative and punishment-related feedback were presented (hence with the activation of defensive motivation), was similar to negative blocks of Experiments 1A and 1B. Likewise, condition C, where informative feedback were used but without monetary loss for slow responses or errors, was similar to neutral blocks used in Experiments 1A and 1B. Relative to Experiments 1A and 1B, conditions B and D were thus new and enabled us to assess the specific contribution of the informative feedback to the CAE. Four specific orders were created a priori and counterbalanced across participants: A-D-C-B, B-C-D-A, C-B-A-D, and D-A-B-C. The procedure was the same for conditions A and C, where trial-by-trial informative feedback was provided, with the notable exception that for condition A, each negative feedback participants received was associated with a 1.5 cent monetary loss; whereas no consequence was associated with negative feedback in condition C. For both conditions, positive feedback was not/never rewarded (with monetary gains). The same procedure was used for conditions B and D, but the feedback provided after each response was always neutral and non-informative. Although participants could not rely on the feedback to infer their accuracy, it marked the end of the trial (similarly to conditions A and C) and importantly, because the same response deadline was used as in conditions A and C, each trial was coded online as correct or incorrect and this information was used to estimate the actual total monetary loss at the end of the block (condition B). Hence, in condition B, each incorrect or slow response was associated with a 1.5 cent monetary loss even though this information was not communicated on a trial by trial basis to the participants. Accordingly, and in analogy with Experiments 1A and 1B (negative blocks), for conditions A and B, a general feedback was provided at the end of each block, indicating "the number of trials associated with too slow RTs", "the number of trials associated with response errors", and thereby "the total amount of money lost", hence punishment motivation was elicited during these blocks. No such general feedback was provided at the end of each block for conditions C and D. At the start of each block, participants were encouraged to make accurate and fast responses.

Prior to the start of the experiment, participants were informed that they could get a maximum payoff of 14 Euro in case they would perform flawlessly (i.e. not receiving any negative feedback during conditions A and B). Hence, they were informed that every negative feedback received during condition A or B would reduce this total amount each time by 1.5 cent. In between blocks, self-paced breaks were allowed. Stimuli were shown in a pseudo-random order within each block to lead to the same number of cC, cI, iC, and iI trials used to compute offline conflict adaptation. Stimuli presentation and data recording were controlled using E-Prime (Version 2.0; Psychology Software Tools Inc., Sharpsburg, PA).

Questionnaires

Similarly to Experiments 1A and 1B, we used the PANAS as main manipulation check for the induction of negative emotion when punishment-related motivation was elicited, and evaluative feedback was used. The PANAS was administered at the end of the practice session for the first time. It was then re-administered after each triplet to measure the corresponding change in mood depending on the specific condition (A, B, C or D). Hence, the PANAS was administered 5 times in total.

Data analyses

Manipulation check. The values of negative and positive affect were obtained from the sum of scores on negative and positive items, respectively. The resulting PANAS values were then submitted to an ANOVA with Punishment (punishment vs. no-punishment), Feedback (informative vs. neutral), and Affect (negative, positive) as within-subject factors.

Analyses of behavioural data based on conflict adaptation. The same procedure was used as in Experiments 1A and 1B. Mean RTs (and error rates) were submitted to an ANOVA with Punishment (punishment vs. No-punishment), Feedback (informative vs. Neutral), Previous Congruency (congruent, incongruent), and Current Congruency (congruent, incongruent) as within-subject factors. A standard alpha level of .05 was used for all statistical tests.

Results

Manipulation check

The ANOVA showed a significant effect of Punishment, with higher subjective ratings in Punishment blocks (conditions A-B) compared with no-Punishment blocks (conditions C-D), $F(1, 28) = 16.991$, $p < .001$, $\eta_p^2 = 0.378$. It also showed a significant effect of Affect, with higher subjective ratings for positive than negative affect, $F(1, 28) = 19.733$, $p < .001$, $\eta_p^2 = 0.413$ (Figure 4A). Importantly, the interaction effect between Punishment and Affect was significant, $F(1, 28) = 9.333$, $p = .005$, $\eta_p^2 = 0.250$. This interaction indicated higher negative feelings in Punishment blocks compared to no-Punishment blocks, $t(28) = 5.494$, $p < 0.001$, $d = 1.02$, 95% CI [1.82, 3.98], whereas positive feelings did not differ between these two conditions, $t(28) = 0.473$, $p = 0.640$, $d = 0.09$, 95% CI [−0.98, 1.56]. Further, this analysis showed that the interaction effect between Feedback and Affect was marginally significant, $F(1, 28) = 4.025$, $p = .055$, $\eta_p^2 = 0.126$. This interaction translated higher negative feelings in informative-Feedback blocks compared with neutral-Feedback blocks (see Figure 4A, left panel),

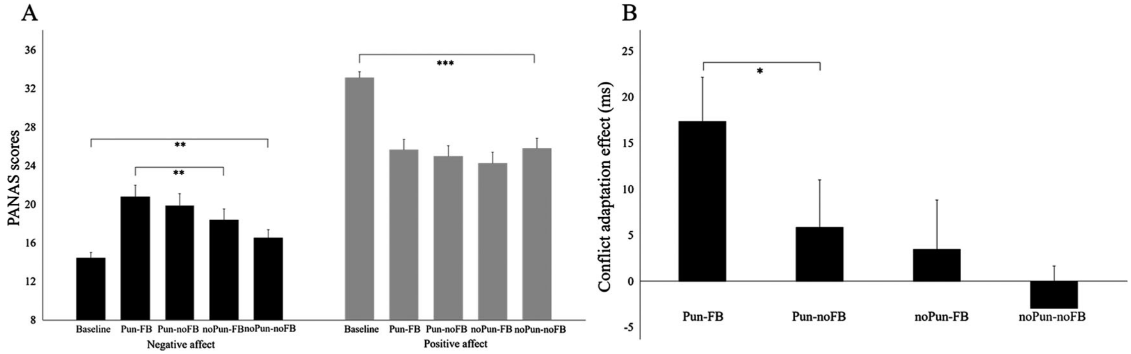

Figure 4. Results of Experiment 2. A. Subjective negative affect was higher for the four experimental conditions compared to the baseline. Importantly, it showed a linear increase depending on the amount and type of integral native emotion, being the highest for the condition with evaluative feedback associated with punishment motivation. By comparison, no such effect was seen for positive affect. The error bar represents the standard error (SE), ***$p < 0.001$, **$p < 0.01$. Pun-FB: Punishment-informative Feedback; Pun-noFB: Punishment-neutral Feedback; noPun-FB: noPunishment-informative Feedback; noPun-noFB: noPunishment-neutral Feedback. B. The CAE was significantly and the highest in the condition with evaluative feedback associated with punishment motivation. Its magnitude decreased when only one of these two components was met. The CAE was absent in the no Punishment-neutral Feedback condition (see Supplementary Materials for statistical analyses run on these CAE scores). The error bar represents the standard error (SE), *$p < 0.05$.

$t(28) = 2.543$, $p < 0.017$, $d = 0.47$, 95% CI [0.27, 2.49], whereas positive feelings did not differ between these two conditions (see Figure 4A, right panel), $t(28) = 0.716$, $p = 0.480$, $d = 0.13$, 95% CI [−0.80, 1.66]. Last, post-hoc paired t-tests showed that levels of negative emotion during the practice session were significantly smaller than those of any other experimental condition, $ts(28) \geq 2.905$, $ps \leq .007$.

Behavioural results

RTs. The ANOVA showed that Punishment was significant, $F(1, 28) = 27.826$, $p < .001$, $\eta_p^2 = 0.498$, with faster RTs in blocks where Punishment was elicited, relative to no-Punishment. The effect of Feedback was also significant, $F(1, 28) = 6.481$, $p = .017$, $\eta_p^2 = 0.188$, with faster RTs in blocks where informative feedback was used, relative to neutral feedback. The effect of Current Congruency was significant, $F(1, 28) = 24.936$, $p < .001$, $\eta_p^2 = 0.471$, with faster RTs for congruent than incongruent trials. Furthermore, the two-way interaction between Previous Congruency and Current Congruency was significant, $F(1, 28) = 4.229$, $p = .049$, $\eta_p^2 = 0.131$. This interaction indicated faster RTs in cC (450 ms) than in iC trials (457 ms), $t(28) = 2.115$, $p = .043$, $d = 0.39$, 95% CI [0.21, 13.40], without significant RT difference between iI (471 ms) and cI trials (471 ms), $t(28) = 0.43$. Importantly, the three-way interaction between Punishment, Previous Congruency and Current Congruency was significant, $F(1, 28) = 5.536$, $p = .026$, $\eta_p^2 = 0.165$, indicating that conflict adaptation was modulated by Punishment (Figure 4B). The three-way interaction between Feedback, Previous Congruency and Current Congruency was also significant, $F(1, 28) = 5.004$, $p = .033$, $\eta_p^2 = 0.152$, indicating that conflict adaptation was modulated by Feedback (Figure 4B). To explore the modulatory effect of Punishment on the CAE, two ANOVAs were performed for Punishment and no-Punishment conditions separately (Figure 5). For the Punishment conditions (Figure 5A), the Current Congruency was significant, $F(1, 28) = 18.964$, $p < .001$, $\eta_p^2 = 0.404$, as well as the interaction effect between Previous Congruency and Current Congruency, $F(1, 28) = 9.391$, $p = .005$, $\eta_p^2 = 0.251$. This interaction was explained by faster RTs in cC (436 ms) than in iC trials (446 ms), $t(28) = 2.624$, $p = .014$, $d = 0.49$, 95% CI [2.20, 17.88], whereas iI trials (456 ms) and cI trials (458 ms) did not differ at the statistical level, $t(28) = 0.538$. By comparison, for no-Punishment conditions (Figure 5B), the Current Congruency was significant, $F(1, 28) = 24.950$, $p < .001$, $\eta_p^2 = 0.471$, but the interaction between Previous Congruency and Current Congruency was not, $F(1, 28) = 0.005$, $p = 0.946$, $\eta_p^2 < 0.001$. To explore further the significant effect of Feedback on the CAE (as revealed by the omnibus ANOVA reported here above), two ANOVAs were run for informative and neutral Feedback conditions separately. For the informative-Feedback conditions, the Current Congruency was significant, $F(1, 28) = 19.936$, $p < .001$, $\eta_p^2 = 0.416$, as well as the interaction between Previous Congruency and Current Congruency, $F(1, 28) = 9.242$, $p = .005$, $\eta_p^2 = 0.248$. This

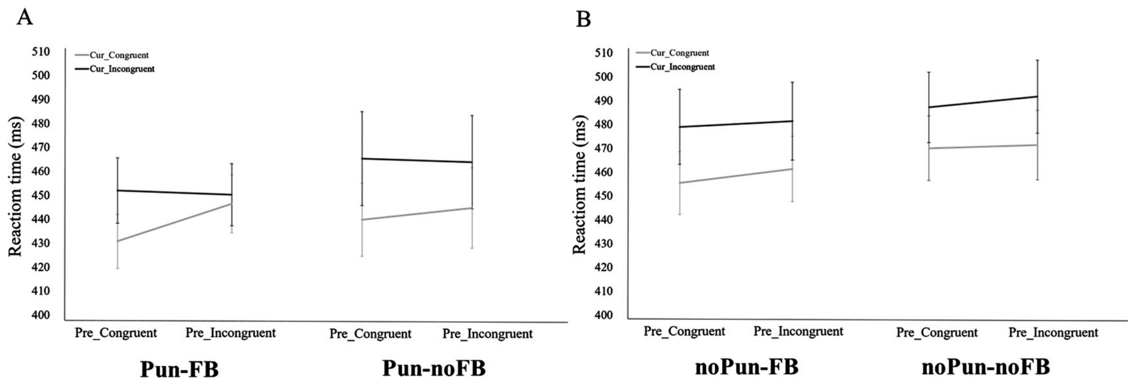

Figure 5. Results of Experiment 2. Behavioural results (RT speed) showing that both punishment motivation and evaluative feedback jointly contributed to the CAE. A. A significant CAE was observed when punishment motivation and evaluative feedback were both elicited (in Pun-informative feedback condition). A trend-significant CAE was found in the Punishment-neutral Feedback condition. B. No reliable CAE was observed in the no Punishment-informative Feedback and no Punishment-neutral Feedback conditions. The error bar represents the standard error (SE).

interaction effect indicated faster RTs in cC (443 ms) than in iC trials (453 ms), $t(28) = 2.804$, $p = .009$, $d = 0.52$, 95% CI [2.90, 18.66], whereas iI (465 ms) and cI trials (465 ms) did not differ from one another, $t(28) = 0.119$. By comparison, for the neutral-Feedback conditions, the Current Congruency effect was significant, $F(1, 28) = 28.640$, $p < .001$, $\eta_p^2 = 0.506$, while the interaction between Previous Congruency and Current Congruency was not, $F(1, 28) = 0.168$, $p = 0.685$, $\eta_p^2 = 0.006$.

Moreover, in order to test our a priori hypothesis more directly (i.e. increased CAE) when integral negative emotion was elicited, corresponding to condition A in the present case, we compared the CAE between the four main conditions, using four separate ANOVAs (with Previous Congruency and Current Congruency as within-subject factors each time). For condition A (Figure 5A, left panel), the Current Congruency was significant, $F(1, 28) = 12.680$, $p < .001$, $\eta_p^2 = 0.312$, as well as the interaction between Previous Congruency and Current Congruency, $F(1, 28) = 12.960$, $p < .001$, $\eta_p^2 = 0.316$, indicating faster RTs in cC (430 ms) than in iC trials (446 ms), $t(28) = 3.367$, $p = .002$, $d = 0.63$, 95% CI [6.11, 25.09], whereas iI (450 ms) and cI trials (452 ms) did not differ from each other, $t(28) = 0.375$. Interestingly, for the three other conditions (B-D) (Figure 5A, right panel for condition B, and Figure 5B, for conditions C-D), the Current Congruency was always significant, $Fs(1,28) \geq 16.418$, $ps \leq .001$, $\eta_p^2s \geq 0.370$, but the interaction effect between Previous Congruency and Current Congruency was never significant, $Fs(1,28) \leq 0.428$, $ps \geq .518$, $\eta_p^2s \leq 0.015$.

Error rates. The ANOVA revealed a significant effect of Feedback, $F(1, 28) = 7.701$, $p = .01$, $\eta_p^2 = 0.216$, and a trend-significant effect of Current Congruency, $F(1, 28) = 3.292$, $p = .08$, $\eta_p^2 = 0.105$. The main effect of Feedback indicated less error when informative-feedback was provided. No other significant effects were found, $Fs(1,28) \leq 2.959$, $ps \geq 0.096$, $\eta_p^2s \leq 0.096$.

Discussion

In this experiment, we broke down integral negative emotion into two main components (i.e. evaluative feedback vs. punishment motivation) to assess which of them was actually responsible for the enhanced CAE observed with this motivational variable. We also used a different interference task compared to Experiments 1A and 1B enabling to rule out effects of feature repetition and contingency learning on conflict adaptation. Manipulation checks confirmed that integral negative emotion was reliably elicited. Importantly, results showed that conflict adaptation was increased with integral negative emotion (and the use of a short ITI), thereby replicating and extending the results found in Experiment 1B.

General discussion

Negative emotion and cognitive control share common variance, especially when conflict detection and (subsequent) resolution (i.e. adaptation) are considered (Stürmer et al., 2011). Yet, which component of negative emotion influences cognitive control remains currently unclear, as discrepant results have previously been reported in the literature (see Table 1 for a review). Moreover, effects of negative emotion on cognitive control likely depend on the actual ITI and hence strength of the carry over effect from the preceding to the current trial (i.e. time scale of cognitive control). In this study, we sought to explore effects of negative emotion (and ITI) on cognitive control when it was conceived primarily as an integral, as opposed to incidental, component.

Across the two experiments, manipulation checks based on subjective ratings (PANAS) confirmed that integral negative emotion was reliably elicited (i.e. scores on the negative affect subscale went up while those on the positive affect subscale went down). Behavioural results showed that integral negative emotion substantially increased cognitive control at short ITI only. Importantly, this effect could not be explained by feature repetitions or contingency learning. Moreover, results of Experiment 2 were important as they helped clarify which component of integral negative emotion accounted for this modulation of cognitive control. More specifically, conflict adaptation was significantly improved when trial by trial evaluative feedback was used and punishment motivation was elicited concurrently; these two conditions being necessary to observe this gain in cognitive control. By comparison, when punishment motivation alone was elicited (but trial by trial evaluative feedback was omitted), conflict adaptation was numerically increased only, suggesting that as such, it was not a sufficient condition to change cognitive control reliably. In this condition, improved cognitive control was presumably not implemented because the trial by trial reinforcement of punishment motivation was omitted. Interestingly and symmetrically, when punishment motivation was removed but evaluative feedback was used, no significant change in conflict adaptation was observed either, in agreement with the results of Experiment 1B (neutral blocks). Moreover, this later result is in line with previous findings showing that negative feedback had no reliable or clear effect on conflict adaptation (Braem et al., 2013; Stürmer et al., 2011). Accordingly, our new results confirm that cognitive control and integral negative emotion probably share common resources or mechanisms to some degree (Dreisbach & Fischer, 2015). However, they add to this existing literature and knowledge by showing that integral negative emotion improves conflict adaptation, pending a short ITI is used and negative emotion is clearly reinforced on a trial by trial basis and associated with punishment-related motivation.

Remarkably, results of Experiment 2 further show that the combination of evaluative feedback with punishment motivation increased conflict adaptation substantially, but this effect did not simply correspond to the sum of these two components, when considered separately (see Figure 4B). This new result suggests that negative emotion, because being integral here, and hence directly related to specific task features (Inzlicht & Al-Khindi, 2012; Spunt, Lieberman, Cohen, & Eisenberger, 2012), might provide a potent motivational cue, which is likely reinforced during the (negative) blocks. Alternatively, it could augment the "salience" of conflict signal and therefore be timely registered by dedicated cognitive control systems (i.e. each time the task is executed), which are responsible for conflict monitoring and resolution, and more generally signalling the need for additional control (Akcay & Hazeltine, 2007; Inzlicht et al., 2015; Inzlicht, Bartholow, & Hirsh, 2013; Kerns et al., 2004).

Accordingly, we surmise that negative feelings (which are exacerbated by the use of small monetary losses contingent on incorrect or slow responses in our study) might be deemed "adaptive", in the sense that they foster enhanced cognitive control (and presumably conflict processing; see Saunders & Inzlicht, 2015). It has been suggested previously that conflict adaptation likely stems from a reactive (as opposed to proactive) control mode, operating on a short time scale (Aben, Verguts, & Van den Bussche, 2017). In agreement with this view, we interpret the improved conflict adaptation triggered by integral negative emotion in our study as the result of enhanced reactive control, which was probably implemented on-line, and rapidly following conflict processing. Further, as our new results suggest, the reactive adjustment in cognitive control driven by integral negative emotion, as captured by the CAE, is not artificially prolonged (such that it would also be visible at the long ITI for example), but instead, it seems to be amplified at the short ITI selectively. In addition, integral negative emotion at long ITI was clearly elicited (as strongly as for the short ITI condition; see manipulation checks based on PANAS and peripheral physiology), yet the CAE remained unchanged in this condition; this null finding therefore cannot be explained by a failure to activate the defensive motivational system in this condition (at the long ITI). Instead, it appears that two pre-requisites need to be met for cognitive control to be influenced by negative emotion: integral negative emotion has to be elicited, but a short ITI has to be used, such that a fast time-scale for trial by trial adjustments in cognitive control is operating.

Although we propose that integral negative emotion likely influences (top-down) conflict-processing and in turn conflict adaptation (Botvinick et al., 2001), we cannot rule out the possibility that (bottom-up) associative processes are also changed by it. Recently, conflict adaptation has been interpreted using such feature-based associative and binding processes (Blais & Verguts, 2012; Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014; Verguts & Notebaert, 2009). Moreover, as suggested recently, it may well be the case that conflict adaptation is modulated by these two families of processes concurrently, acting at different levels or scales, and showing sometimes dissociable effects (Egner, 2014, 2017; Weissman, Hawks, & Egner, 2016). Whether integral negative emotion influences conflict adaptation via a top-down conflict processing route directly, or alternatively, via concurrent changes in bottom-up associative processes, remains to be elucidated, however.

The observation that conflict adaptation is modulated by the length of the ITI is not odd, but accords well with previous studies in the literature: the CAE is usually most pronounced using short ITIs and tends to decay sharply when using longer intervals (Egner et al., 2010; Van Steenbergen et al., 2010; Van Steenbergen, Band, & Hommel, 2012). Changes in the strength of conflict adaptation have also been reported previously depending on the use (and actual valence) of interspersed performance feedback. For instance, Van Steenbergen et al. (2009) found that negative feedback influenced conflict adaptation, when this feedback was presented directly after the response. In comparison, Stürmer et al. (2011) used a 500-ms interval, and did not find an influence of feedback on conflict adaptation.

Alternatively, the implementation of enhanced conflict-driven adjustment during the encounter of integral negative emotion could be regarded as a form of emotion regulation (Dignath & Eder, 2015; Dreisbach & Fischer, 2015), as opposed to cognitive control per se. Although remaining largely speculative at this stage, it is feasible that this enhanced adaptive control triggered by integral negative emotion at a short ITI might reflect a compensatory mechanism, whereby participants would actively try to reduce these negative experiences or feelings in this condition (Dignath & Eder, 2015; Gyurak, Gross, & Etkin, 2011; Inzlicht et al., 2015; Schouppe, De Houwer, Ridderinkhof, & Notebaert, 2012). Such an interpretation accords well with the affect alarm model of self-control, in which negative information can be viewed as adaptive to some extent (i.e. when low to mild doses of negative emotion are used with healthy participants), acting like a guiding signal that there is something wrong happening in the environment somehow, and an adjustment or compensation is therefore timely required to overcome (and change) this feeling (Inzlicht et al., 2013; Schmeichel & Inzlicht, 2013). As our results suggest, this emotion regulation effect resulting from the elicitation and experience of integral negative emotion appears to be time sensitive, however. No improved conflict adaptation was seen when a long ITI was used, suggesting that emotion regulation likely influenced cognitive control when the affective or aversive connotation of conflict processing was still present or lingering (Fritz & Dreisbach, 2015). Along the same lines, a mediation by emotion regulation processes might also explain why positive emotion can even be elicited (and measured using implicit and priming measures) after successfully resolving conflict (Schouppe et al., 2015).

Hence, it remains to determine in future studies whether the change in CAE with integral negative emotion reflects enhanced cognitive control per se (i.e. an attempt to reduce conflict), or instead, corresponds to an active attenuation of the negative (or even aversive) subjective feelings experienced in negative blocks, or perhaps a blend of both. To disentangle between these two explanations (being not necessarily mutually exclusive), not only the amount of negative emotion but also the actual strategies used by participants to deal with it (e.g. coping style and/or emotion regulation; see Gross, 2002; Gross & Jazaieri, 2014) could be measured more systematically in future studies and related to possible changes in CAE by means of correlation analyses for example. Further, it may be the case that the change and improvement in cognitive control with integral negative emotion at the short ITI depends on specific dispositions or cognitive styles, such as the dichotomy between action-oriented vs. state-oriented individuals (Fischer, Plessow, Dreisbach, & Goschke, 2015). Whereas action-oriented individuals might be better to use directly the conflict as control signal and thereby influence positively cognitive control, state-oriented individuals might process the affective values of the signal but without using it directly to change and improve cognitive control. Therefore, it might be useful in future studies to adopt an inter-individual differences approach, and assess the extent to which specific dispositions or styles may influence the link between cognitive control and integral negative emotion, as found here using the CAE. More generally, such research efforts would be valuable given that changes or difficulties in conflict adaptation have previously been attributed to either specific emotional or cognitive deficits (de Galan, Sellaro, Colzato, & Hommel, 2014). Last, although we argued that these changes are probably adaptive (in healthy adult participants), it remains to assess under which conditions they might become maladaptive, and perhaps diagnostic of specific disorders, such as generalised anxiety or major depression (Grupe & Nitschke, 2013). Presumably, depending on its intensity, duration, controllability and origin/nature, integral negative emotion could be associated with either beneficial or detrimental effects on cognitive control (Gross & Jazaieri, 2014).

To conclude, the current study informs about the boundaries within which negative emotion dynamically influences conflict-driven adaptive control. We found evidence for enhanced cognitive control (using the CAE) when integral negative emotion was elicited, and a short ITI was used, exclusively, suggesting that it operated at a short time scale. Further, we clarified that two main components of integral negative emotion, namely evaluative feedback contingent on task performance having an enhanced punishment-related motivational significance, had to be combined with one another to observe this change and gain in cognitive control. Speculatively, this effect could reflect enhanced cognitive control per se (i.e. amplification of control processes), or alternatively, an attempt to downplay the experienced negative emotion in this condition (i.e. emotion regulation); these two different accounts being not necessarily mutually exclusive.

Disclosure statement

No potential conflict of interest was reported by the authors.

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