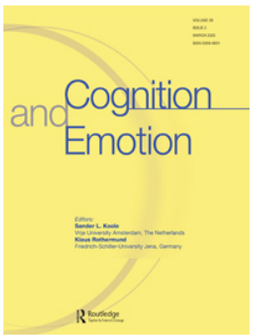

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Exploring an emotional basis of cognitive control in the flanker task

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ABSTRACT

The present study investigated the influence of emotional stimuli in the flanker task. In six experiments, separate influences of anticipating and reacting to valence-laden stimuli (affective pictures or facial expressions) on the flanker effect and its sequential modulation (also known as conflict adaptation) were examined. The results showed that there was little evidence that emotional stimuli influenced cognitive control when positive and negative stimuli appeared randomly during the flanker task. When positive and negative stimuli were separated between different participant groups in order to exclude a possible contamination from the effect of one valence to that of another, the sequential modulation was reduced when valence-laden stimuli were anticipated or had been presented on a preceding trial, regardless of the valence of the stimuli. A similar pattern was also obtained with facial expressions but only for response accuracy and only after valence-laden stimuli were presented on a preceding trial. The influences of anticipating and reacting to emotional stimuli were only partially replicated in the final two experiments where the arousal and valence of affective pictures were manipulated orthogonally. The lack of consistent influences of emotional stimuli on the flanker effect challenges the existing theories that implicate affective contributions to cognitive control.

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Dual-process framework; conflict adaptation; affect; valence; arousal

Introduction

Although the psychological study of emotion dates back to as far as Charles Darwin's era (Snyder et al., 2010), systematic investigation of the emotional bases of cognitive control is a relatively recent development (e.g. Braem et al., 2013; Dreisbach & Goschke, 2006). One of the popular experimental paradigms in this endeavor has been Eriksen's flanker task (Eriksen & Eriksen, 1974). In the flanker task, participants are presented with the visual target and flanking noise stimuli (*flankers*). In some trials, the flankers are stimuli that are associated with the same response as the one that is required to the target (*compatible trials*). In other trials, the flankers are stimuli that are associated with a response that is different from that required to the target (*incompatible trials*). Responses are faster (and are often more accurate) on compatible trials than on incompatible trials, which is known as the *flanker effect*. The flanker effect is thought to reflect the ability to focus on the task goal while ignoring distractors (e.g. Coles et al., 1985; Gratton et al., 1992), a hallmark of cognitive control. Several recent studies reported the involvement of emotional and affective processes in the flanker task (e.g. Kanske & Kotz, 2010; Landman & van Steenbergen, 2020; Schuch & Koch, 2015; van Steenbergen et al., 2010; Zeng et al., 2017). There is a wide variety of procedures and types of stimuli that have been used in these studies, and the results are not always consistent (Cohen & Henik, 2012; Dignath et al., 2020; Zhang et al., 2023). In a series of six experiments, the present study examined the robustness of these findings by using two types of stimuli (affective pictures and facial expressions) that

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are often used in the studies of human affective processing. To explore the emotional basis of cognitive control in a more fine-grained manner, the present study probed separate roles of anticipating and reacting to spontaneous emotional events in the flanker task (Yamaguchi & Nishimura, 2019).

Emotional influences on cognitive control in the flanker task

The flanker task has played an important role in developing a popular neurocognitive theory of cognitive control, the *dual-process theory* (Botvinick et al., 2001; Braver, 2012). The theory proposes that there are two major processes of cognitive control, proactive and reactive control, which are associated with unique brain networks. *Proactive control* depends on the actor's anticipation of the task demand. If a higher probability of conflict is anticipated for an incoming trial, the prefrontal cortex (PFC) increases selective attention and weighs more on the task-relevant information. This reduces the impact of noise stimuli and, thus, the flanker effect. Proactive control has been implicated to explain the findings that the flanker effect is smaller if incompatible trials occur more often than compatible trials or if a cue indicates that the incoming trial is more likely to be an incompatible trial than a compatible trial (Gratton et al., 1992). *Reactive control* depends on the anterior cingulate cortex (ACC) that monitors and registers conflicts in cognitive processes. When a conflict is detected on an incompatible trial where the target and flankers indicate different responses, the ACC sends a signal to the PFC to adjust selective attention to the relevant aspects of the task. Selective attention is strengthened and allows the actor to reduce the impact of subsequent conflicts in cognitive processing on performance, thus reducing the flanker effect. Reactive control has been implicated to explain a robust observation that the flanker effect is smaller on trials that follow an incompatible trial than on trials that follow a compatible trial (Gratton et al., 1992). Several different accounts of this effect of preceding trial type have been proposed, each receiving empirical support. Different researchers also call the phenomenon with different names to reflect their theoretical commitment (e.g. conflict adaptation, episodic learning, feature integration; see Braem et al., 2019; Egner, 2014), but we remain neutral as to the mechanism by which the sequential modulation of the flanker effect is produced. Hence, we will refer to this pattern of results simply as the *sequential modulation* of the flanker effect.

In principle, proactive control and reactive control (or any other possible mechanisms of the sequential modulation) can operate simultaneously (Braem et al., 2019; Yamaguchi et al., 2018), but researchers have also considered proactive and reactive control as two modes of cognitive control (Braem et al., 2013; Chiew & Braver, 2011; Dreisbach & Goschke, 2006). A *proactive mode* invokes a more stable and sustained focus of attention throughout a long period of time, which increases the stability of task performance in exchange with flexibility to adapt to the changing environment. In contrast, a *reactive mode* invokes a transient and elusive focus of attention, which increases the flexibility to adapt to the changing environment in exchange with the stability of performance. This theoretical view predicts that the sequential modulation of the flanker effect would be reduced with a proactive mode, whereas the sequential modulation would increase with a reactive mode. More recently, the dual-process theory has been linked to affective processes more explicitly, according to which the ACC monitors a broader range of affective signals. In this view, conflict is registered as an aversive signal that causes adjustment of selective attention (Botvinick, 2007). Hence, it proposes that negative affect and moods also strengthen conflict adaptation (i.e. increase reactive control), whereas positive affect and moods weaken conflict adaptation (i.e. decrease reactive control). A related proposal is that positive affect shifts the control to a proactive mode that results in a sustained increase of selective attention, at a cost of flexible reactive control (Chiew & Braver, 2011). In both cases, the dual-process theory predicts that positive affective states or stimuli would weaken reactive control and reduce the sequential modulation of the flanker effect, whereas negative affective states or stimuli would reinforce reactive control and increase the sequential modulation.

Several studies have examined the predictions of the dual-process theory, but they have provided mixed support (for a review, see Dignath et al., 2020). In support of the dual-process theory, some studies reported smaller sequential modulations of the flanker effect (i.e. decreased reactive control) under positive moods as compared to those under negative moods (Schuch & Koch, 2015; van Steenbergen et al., 2010). However, subsequent studies have shown that, when responding to the colors of word

stimuli, there was an increase in the sequential modulation of the flanker effect for both positive and negative meanings of words as compared to neutral meanings (Landman & van Steenbergen, 2020; Zeng et al., 2017). Instead, the researchers proposed that it was high arousal stimuli, rather than the valence of stimuli, that increased the sequential modulation, although the influences of mood states were not found to depend on arousal (van Steenbergen et al., 2010). Therefore, the dual-process theory has not received unequivocal support from previous studies with regard to its prediction about affective influences on cognitive control.

Dignath et al. (2020) carried out an extensive review of the literature and distinguished experimental manipulations of *phasic* and *tonic* affective states (for the distinction between phasic and tonic *cognitive* states for the regulation of emotional stimuli, see Grützmann et al., 2019). Phasic affective states are transient states that may result from momentary presentation of affective stimuli (e.g. viewing an emotion-provoking picture on random trials), whereas tonic affective states are sustained states that may result from changing moods of participants. They concluded that studies have provided more direct evidence that tonic affect influences the sequential modulation, but evidence supporting influences of phasic affect is ambiguous. The authors proposed a few possible factors that might have contributed to the mixed results. For example, they observed that increased sequential modulations were reported when affective stimuli were presented simultaneously with task-relevant stimuli (Zeng et al., 2017), but there was little influence of affective stimuli when they were presented separately from task-relevant stimuli (Dignath et al., 2017; also see Tannert & Rothermund, 2020). They also suggested that positive stimuli could act as a background of negative stimuli to enhance the registration of the latter (Dreisbach et al., 2019), although this has not always been found (Zhang et al., 2019).

Influences of positive rewards on cognitive control

According to the dual-process theory, affective signals are monitored by the ACC and modulate the activities of the PFC. Hence, it might be said that affective signals have an effect on cognitive control by modulating motivational processes. Researchers have advocated a close link between the influences of affect and reward on cognitive control (see Dreisbach & Fischer, 2012; Notebaert & Braem, 2016), and some studies have shown that, when rewards were given on random trials irrespective of task performance, rewards reduced the sequential modulations of the flanker effect (i.e. reduced reactive control; van Steenbergen et al., 2009; Yamaguchi & Nishimura, 2019), consistent with the dual-process theory. However, other studies found that, when rewards were contingent on task performance (e.g. rewarded if responses were correct or quick by some criteria), rewards increased reactive control (Braem et al., 2012; Fröber & Dreisbach, 2014). These latter studies used a task switching procedure (Braem et al., 2012) or a continuous-performance task (Fröber & Dreisbach, 2014) and suggested that both random rewards and positive affect increased reactive control. Again, these findings appear to contradict the dual-process theory. In the flanker task, little influence of performance-contingent rewards on the sequential modulation of the flanker effect was found, whereas random rewards reduced the sequential modulation (Yamaguchi & Nishimura, 2019), which is consistent with the dual-process theory but only partly.

In addition to these observations, a previous study has shown that reactive control is modulated in anticipation of a positive reward (i.e. by precuing an incoming trial as a rewarding trial) but not as a reaction to a received reward (Yamaguchi & Nishimura, 2019). Such a finding echoes with recent studies showing that cognitive control settings are sensitive to changes in the reward prospect (i.e. increasing or decreasing rewards as compared to previous rewards) rather than the value of a received reward alone (Fröber & Dreisbach, 2016; Fröber et al., 2019; Hefer & Dreisbach, 2017). The effect of rewards involves affective and motivational influences on cognitive control (Fröber & Dreisbach, 2014; Notebaert & Braem, 2016), and it is not entirely clear whether these findings are based on affective or motivational processes.

The present study

As per the recent review (Dignath et al., 2020), previous studies have provided fairly complex, and often contradictory, patterns of results as to whether phasic affective states influence reactive control. In some of the studies using the flanker task, emotional stimuli were the meanings of words that were irrelevant to the task (Landman & van Steenbergen, 2020; Zeng et al., 2017), and they found that the sequential

modulation increased for both positive and negative word meanings as compared to that for neutral word meanings. In other studies (e.g. Braem et al., 2013; Fröber & Dreisbach, 2014), affective pictures from the International Affective Picture System (IAPS; Lang et al., 2008) have been used to manipulate phasic affect in task-switching and continuous performance tasks, but their influences on the flanker task remain unknown. There have also been studies using facial expressions as valence-laden stimuli, which appear to produce robust effects on visual attention even when they are irrelevant to the task (e.g. Hodsoll et al., 2011). In the flanker task, two studies have used facial expressions as contextual cues to indicate the probability of compatible and incompatible trials (Cañadas et al., 2016; Zhang et al., 2019). One of the studies found that facial expressions were effective in cuing the probability of incoming trial type (Cañadas et al., 2016), but the other study did not (Zhang et al., 2019). Neither of these studies reported any direct influence of these emotional stimuli on the flanker effect or its sequential modulation. In addition, other studies used facial expressions as target and flankers, and smaller flanker effects for negative facial expressions than for positive faces were reported in some studies (fearful vs. happy faces, Grose-Fifer et al., 2013; schematic flown vs. smiley faces; Fenske & Eastwood, 2003), but not in others (e.g. Mueller & Kuchinke, 2016). None of these flanker-task studies examined the affective influence on the sequential modulation of the flanker effect. Furthermore, none of these previous studies examined explicitly how the anticipation of affective events influences cognitive control in the flanker effect.

Most previous studies examined emotional influences on cognitive control as participants reacted to emotional stimuli. While emotions arise as reactions to ongoing events (e.g. perceiving emotion-eliciting pictures), they can also occur by anticipating such events. For example, Vanderhasselt et al. (2014) found that anticipating emotional events results in larger pupillary responses, which is an indication of sustained attention for subsequent online processing of emotional stimuli. To examine separate roles of anticipating an emotional event and reacting to the anticipated emotional event in the flanker task, the present study adopted the precuing procedure developed by Yamaguchi and Nishimura (2019). Namely, the role of anticipation was examined by analyzing the flanker effect (and its sequential modulation) on the cued trials for which responses were made before an emotional stimulus was presented. The role of reaction to an emotional stimulus was examined by analyzing the flanker effect (and its sequential modulation) on the trial that immediately followed a cued trial. This distinction is particularly important because previous studies of affective influences on the flanker task have not disentangled the roles of anticipatory and reactive processes, which map onto two fundamental processes of cognitive control in some theories such as the dual-process theory. In Yamaguchi and Nishimura's study, anticipating a random reward reduced the sequential modulation of the flanker effect (also see van Steenbergen et al., 2009). Because influences of reward could be motivational or affective (e.g. Chiew & Braver, 2011; Dreisbach & Fischer, 2012), it is not clear whether affective stimuli, which had no motivational effect, are sufficient to influence cognitive control. For this purpose, the present study used two types of valence-laden stimuli, affective pictures from the IAPS and facial expressions (fearful vs. happy) from the Chicago Face Database (CFD; Ma et al., 2015), because different types of affective stimuli could entail different types of emotional responses (e.g. Wangelin et al., 2012). Affective pictures are meant to evoke emotional reactions in the observers, but facial expressions are social cues that may not necessarily evoke the same emotional reactions in the observers as the ones being expressed. Therefore, we examined the influences of affective pictures and facial expressions in separate experiments that were run in parallel.

We report six experiments. Experiments 1 and 2 presented positive and negative stimuli on random trials in the flanker task, which effectively manipulated phasic affect (Dignath et al., 2020). In Experiments 3 and 4, each participant only encountered either positive or negative stimuli. The consistency of valence across trials would lead to an expectation of a particular valence event (an equivalent finding was reported when reward was manipulated between blocks; see Yamaguchi & Nishimura, 2019), which would lead to sustained affective state (i.e. tonic affect). Experiments 5 and 6 used the IAPS with each participant only receiving positive or negative trials. Stimuli in these experiments were of high arousal for half of these trials and of low arousal for the other half. These experiments addressed a recent proposal that the sequential modulation of the flanker task depended on arousal but not valence (Landman & van

Steenbergen, 2020; Zeng et al., 2017). Because the previous studies did not explicitly manipulate arousal among emotional stimuli, the present study provides the first attempt at explicitly manipulating arousal independent of valence for both positive and negative stimuli and teasing apart their influences in the flanker task systematically.

Experiments 1 and 2

Experiments 1 and 2 examined the influences of valence-laden stimuli in the flanker task. Experiment 1 used the affective pictures from the IAPS (Lang et al., 2008), and Experiment 2 used facial expressions (fearful and happy faces) from the CFD (Ma et al., 2015). Both experiments used the experimental design of Yamaguchi and Nishimura's (2019) flanker task, which allowed separating the roles of anticipating and reacting to emotional stimuli. In the experiments, one third of the trials presented a positive or negative picture at the end of the trial. These *emotional trials* were precued, so that participants could anticipate an incoming affective picture on that trial. Because participants were yet to experience the emotional event when they performed the trial, any differences on these emotional trials from non-emotional trials would reflect the anticipation of a valence-laden stimulus. Note that the precues only informed of the occurrence of a valence-laden stimulus but not its valence content, so that participants could only anticipate an unspecified affective event on that trial but could not anticipate whether it would be a positive or negative image. Furthermore, precued emotional trials were always immediately followed by a non-emotional trial, for which no valence-laden stimulus was presented. Hence, any difference between non-emotional trials that followed positive pictures and those that followed negative pictures would reflect the reaction to the affective content of the preceding valence-laden stimulus.

Because the literature has provided mixed results as to the affective influences on the flanker effect, it is not straightforward to predict a particular pattern of results in the present experiments. With affective word meanings (Landman & van Steenbergen, 2020; Zeng et al., 2017), any phasic affective events (positive or negative) would increase the sequential modulation of the flanker effect as compared to non-affective events. In contrast, the dual-process theory predicts a reduced sequential modulation after positive stimuli (Botvinick, 2007; Chiew & Braver, 2011; also see Schuch & Koch, 2015; van Steenbergen et al., 2010). Moreover, none of the previous studies have separated the roles of anticipating and reacting to valence-laden stimuli, except for Yamaguchi and Nishimura (2019) who showed reduced sequential modulation in the anticipation of positive rewards but not reaction to it. In the present experiment, participants were presented with positive and negative affective stimuli in an unpredictable manner. These emotional events would invoke phasic affect rather than tonic affect. Therefore, the present experiments provided the first test of anticipating and reacting to phasic affective states on the flanker effect and its sequential modulation.

Method

Participants

To detect a medium effect size at statistical power of .8, at least 34 participants would be required for the present design.[1] We recruited 48 participants in each of the two experiments from the Edge Hill University community (Experiment 1: 31 females; mean age = 20.53, *SD* = 2.37, range = 18–30; Experiment 2: 30 females; mean age = 20.38, *SD* = 1.98, range = 18–27). They reported having normal or corrected-to-normal visual acuity, normal color vision, and normal hearing. Participants were paid £3 for participation in the present experiment. All participants provided an informed consent before participation, and the experimental protocol was approved by the Research Ethics Committee of the Department of Psychology at Edge Hill University.

Apparatus and stimuli

The apparatus consisted of a 23-inch widescreen computer monitor and a personal computer. Target and flanker stimuli were squares (2.6 cm in side) colored in green or red against a light gray background. Responses were registered by pressing two keys ("*f*" *and* "*j*" keys) on a standard desktop QWERTY keyboard.

In Experiment 1, 50 images were selected from the IAPS (Lang et al., 2008); 25 images had positive valence ratings and 25 images had negative valence ratings (see Table A1 in the Appendix 1). The mean rating scores for the positive and negative images were matched for arousal (*M*s = 5.57 and 5.52 for positive and negative images, $t(48) = .42$, $p = .678$) and the magnitude of valence[2] ($M = 2.71$ and 2.80 for positive and negative images, $t(48) = 1.23$, $p = .226$). The image

subtended 94% of the computer monitor; the image size on the display was 37.5 cm in width and 27.8 cm in height.

In Experiment 2, photographs of 72 Caucasian individuals (36 females and 36 males) were selected from the Chicago Face Database (CFD; Ma et al., 2015), with happy and fearful facial expressions of each individual (144 photographs in total). These photographs were divided into two sets (A and B) of 36 individuals (18 male and 18 female) which were matched for perceived age, trustworthiness, attractiveness, and ratings of their fearful and happy expressions (see Table A2 in the Appendix 1). One group of participants saw happy expressions from Set A and fearful expressions from Set B; the other group of participants saw happy expressions from Set B and fearful expressions from Set A, so that the same individual always expressed one emotion for a given participant. Participants were randomly assigned to one of the two stimulus sets. The image size on the display was 32 cm in width and 21 cm in height.

Procedure

The experiment was conducted individually in a cubicle under normal fluorescent lighting. Participants sat in front of the computer monitor and read on-screen instructions. The instructions emphasised both speed and accuracy of responding to the target and warned that participants would be presented with positive or negative images on a portion of the trials, and some of these images might make them feel nauseous or disgusted. They were allowed to withdraw from the experiment whenever they felt unable to continue. As long as they continued with the experiment, participants were asked not to look away from these images. Participants were also informed that each trial started with a black fixation cross (+) or a white X, and the latter indicated an occurrence of an image at the end of the trial; thus, the white X served as a precue indicating a trial with an emotional image (*emotional trial*), as opposed to a trial without an image (*non-emotional trial*).

Each participant performed a block of 20 practice trials, which consisted of 6 emotional trials (3 positive and 3 negative) and 14 non-emotional trials. The practice trials were followed by four blocks of 152 test trials (50 emotional trials and 102 non-emotional trials in each). Each emotional trial was preceded and followed by non-emotional trials. No more than three non-emotional trials could occur in succession. The first and last trials in each block were always non-emotional trials, and the first trial in each block was excluded from the analysis.

The sequence of the display events is depicted in Figure 1. A non-emotional trial started with a fixation cross at the center of screen for 1000 ms. The fixation display was followed by an array of three squares. Participants responded to the color of the central square (target) and ignored the adjacent squares (flankers). The two flankers were always identical. On half of the trials, the target and flankers were in the same color (cANOVAs separately. All variable-sompatible trials), and they were different in the other half (incompatible trials). The target color was green on half of the trials and red on the other half. Participants responded within a 2000-ms response window after the target onset. If the response was incorrect, the message "Error!" was shown at the screen center; if no response was made within the response window, the message "Faster!" was presented. The feedback message lasted for 500 ms. A blank display was presented for 500 ms if the response was correct. There was an additional 500-ms blank display before the next trial started. An emotional trial started with a white ×(in the place of the fixation cross on a non-emotional trial) for 1000 ms, which was followed by the target display consisting of a target and two flankers. After the feedback display, a positive or negative image was presented for 2000 ms. A 500-ms blank followed the image before the next trial started. Response time (RT) and accuracy were recorded on each trial. RT was the interval between onset of a target and a depression of a response key. Error trials were those for which a wrong key was pressed.

Data analysis

Mean RT for correct responses and percentages of error trials (PE) were computed for each participant. Trials were discarded if no response was made, RT was less than 200 ms, or they followed an error response or no response. The sequential modulation of the flanker effect was computed by subtracting the flanker effect after incompatible trials from the flanker effect after compatible trials. The data were analysed in terms of (1) the role of anticipating an emotional stimulus and (2) the role of reacting to an emotional stimulus. For the first analysis, RT and PE were analysed only for emotional and non-emotional trials that followed a non-emotional trial. All trials that followed an emotional trial were excluded. Note that

Figure 1. Illustrations of the trial sequences for non-emotional trials and emotional trials (with affective pictures in Experiment 1 and emotional faces in Experiment 2). There was a feedback message for error trials or trials with no response in the first blank display following the flanker stimuli, but no message was shown for correct trials. Examples above illustrate correct trials. The images are for an illustration and are not scaled accurately to the actual display size.

this analysis did not distinguish between positive and negative emotional stimuli because participants were only precued of an emotional stimulus but not of the emotional content of the stimulus. Hence, the valence of the stimulus should not have any influence on their performance. RT and PE were submitted to 2 (Trial Type: emotional vs. non-emotional) × 2 (Previous Compatibility: compatible vs. incompatible) × 2 (Current Compatibility: compatible vs. incompatible) ANOVAs separately. All variables were within-subject factors. For the second analysis, only non-emotional trials that followed emotional trials or non-emotional trials were used to compute RT and PE. They were submitted to 3 (Previous Trial Type: positive image vs. negative image vs. no image)×2 (Previous Compatibility: compatible vs. incompatible) × 2 (Current Compatibility: compatible vs. incompatible) ANOVAs. The analyses were carried out with R Studio (R Core Team, 2021), and the results of ANOVAs are summarized in Appendix 2. We also carried out Bayesian ANOVAs with the same structures as above, which is summarised in Appendix 3.

Openness and transparency

For all experiments reported in this article, the experimental programmes, stimuli, data, analysis scripts, and preprints can be found in the OSF project page (https://osf.io/y54pu/). The analyses reported below are not pre-registered.

Results

Experiment 1

The results of the ANOVAs are summarised in Table A4 in Appendix 2. Figure 2 summarizes RT and PE as well as the sequential modulations in RT and PE. The overall error rate was 2.62%, and 2.93% of all trials were discarded for the analyses for the reasons described in the Analysis section above.

The role of anticipation. For RT, there were significant main effects of Current Compatibility, $F(1, 47) = 51.60$, $MSE = 1183.91$, $p < .001$, $\eta_p^2 = .523$, and of Previous Compatibility, $F(1, 47) = 11.64$, $MSE = 597.08$, $p = .001$, $\eta_p^2 = .198$, and they also interacted,, $F(1, 47) = 39.23$, $MSE = 445.06$, $p < .001$, $\eta_p^2 = .455$. Thus, although there was a 25-ms overall flanker effect ($Ms = 481$ ms vs. 506 ms, for compatible and incompatible trials; $SEs = 11.13, 12.53$), the effect depended on whether the preceding trial was compatible or incompatible. The flanker effect was larger after a compatible trial ($M = 39$ ms, $SE = 4.29$) than after an incompatible trial ($M = 12$ ms, $SE = 3.94$), yielding a 27 ms of the sequential modulation. There was also a main effect of Trial Type, $F(1, 47) = 9.06$, $MSE = 736.12$, $p = .004$, $\eta_p^2 = .162$, which reflected the outcome that responses were longer when an emotional trial was cued ($M = 498$ ms, $SE = 11.79$) than when a non-emotional trial was cued ($M = 489$ ms, $SE = 11.81$). However, there was no significant

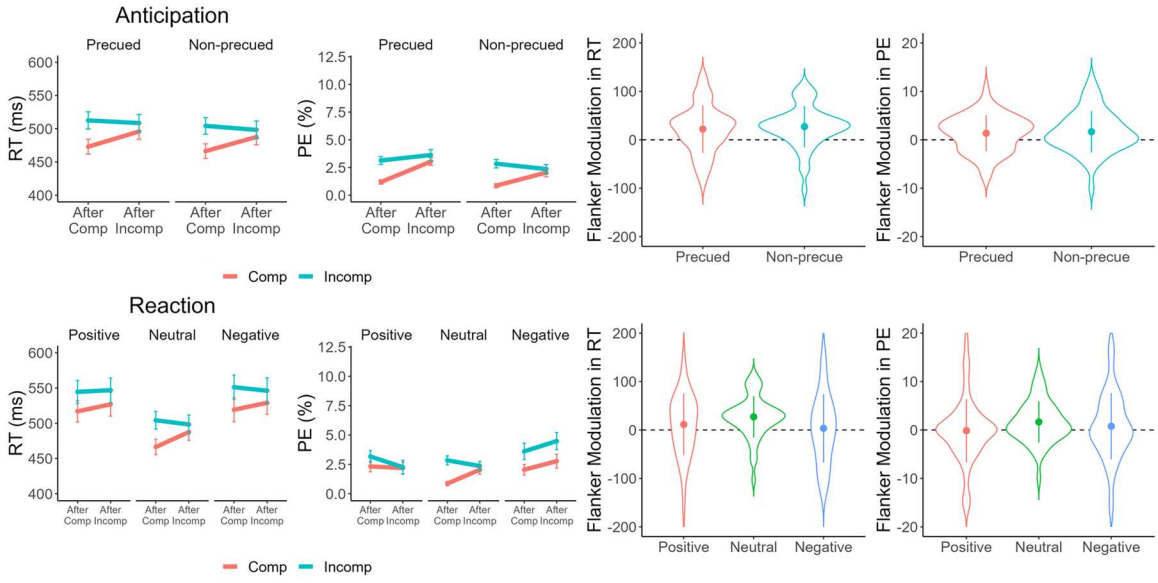

Figure 2. Mean response times (RT), percentage of error trials (PE), and the amount of sequential modulation of the flanker effect (Flanker Modulation) in RT and PE in Experiment 1. The top panels show the results of anticipating emotional stimuli, and the bottom panels show the results of reacting to emotional stimuli. In the line graphs, error bars represent one standard error of the means; in the violin plots, the dots represent the grand means, and the lines around the grand means represent one standard error of the individual means.

interaction involving Trial Type. Importantly, the sequential modulation was 26 ms for emotional trials and was 27 ms for non-emotional trials. Thus, anticipation of an emotional trial only slowed responding, but it did not influence the flanker effect or its sequential modulation.

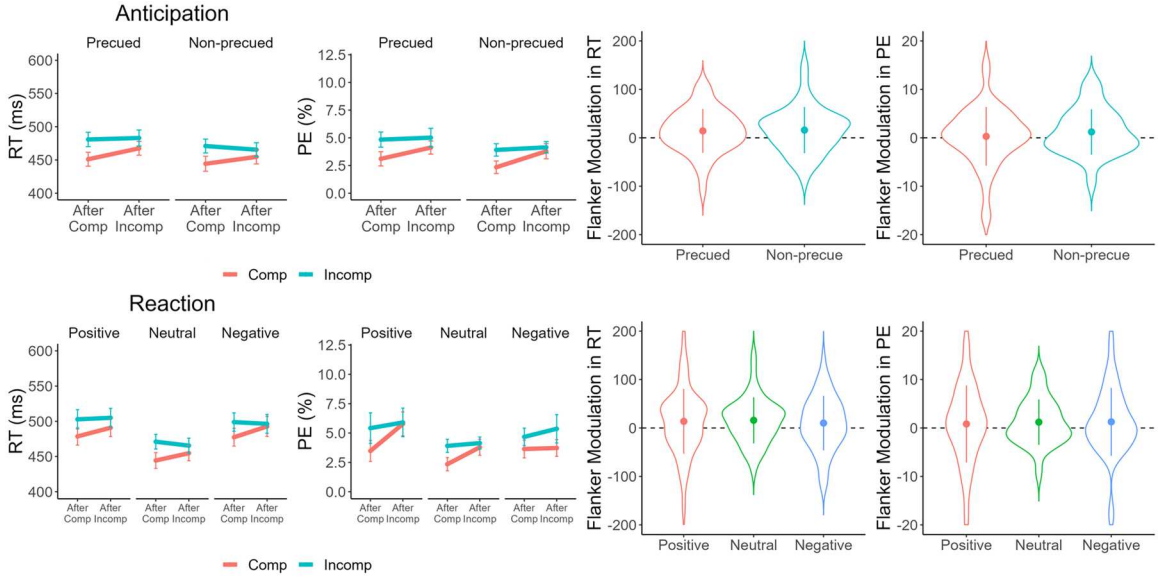

Figure 3. Mean response times (RT), percentage of error trials (PE), and the amount of sequential modulation of the flanker effect (Flanker Modulation) in RT and PE in Experiment 2. The top panels show the results of anticipating emotional stimuli, and the bottom panels show the results of reacting to emotional stimuli. In the line graphs, error bars represent one standard error of the means; in the violin plots, the dots represent the grand means, and the lines around the grand means represent one standard error of the individual means.

For PE, there were also main effects of Current Compatibility, $F(1, 47) = 20.07$, $MSE = 6.97$, $p < .001$, $\eta_p^2 = .299$, and of Previous Compatibility, $F(1, 47) = 9.47$, $MSE = 5.85$, $p = .003$, $\eta_p^2 = .168$, and these variables interacted, $F(1, 47) = 11.00$, $MSE = 4.97$, $p = .002$, $\eta_p^2 = .190$. The flanker effect was 1.96% ($SE = .34$) after a compatible trial and .45% ($SE = .37$) after an incompatible trial, yielding a 1.51% of the sequential modulation. There was a main effect of Trial Type, $F(1, 47) = 9.63$, $MSE = 5.16$, $p = .003$, $\eta_p^2 = .170$. PE was larger when an emotional trial was cued ($M = 2.75\%$, $SE = .24$) than when a non-emotional trial was cued ($M = 2.03\%$, $SE = .23$). The variable interacted with Previous Compatibility; the effect of anticipating an emotional trial was larger after an incompatible trial ($Ms = 3.34\%$ vs. 2.21% for emotional and non-emotional trials; $SEs = .23$ and .20) than after a compatible trial ($Ms = 2.16\%$ vs. 1.86% for emotional and non-emotional trials; $SEs = .34$ and .33). As in RT, however, Trial Type did not influence the sequential modulation; the sequential modulation was 1.36% for emotional trials and 1.66% for non-emotional trials.

The role of reaction. For RT, there was a main effect of Current Compatibility, $F(1, 47) = 48.43$, $MSE = 1749.55$, $p < .001$, $\eta_p^2 = .508$, and this interacted with Previous Compatibility, $F(1, 47) = 13.21$, $MSE = 747.34$, $p < .001$, $\eta_p^2 = .219$. The flanker effect was larger after a compatible trial ($M = 33$ ms, $SE = 3.92$) than after an incompatible trial ($M = 16$ ms, $SE = 4.39$), yielding a 17-ms of the sequential modulation. There was a main effect of Previous Trial Type, $F(2, 94) = 25.25$, $MSE = 5374.08$, $p < .001$, $\eta_p^2 = .350$; responses were generally slower on trials after an emotional image ($Ms = 534$ and 536 ms after positive and negative images, respectively; $SEs = 15.78$ and 16.52) than trials after a non-emotional trial ($M = 489$ ms, $SE = 11.81$). The sequential modulation was 8 ms after a positive image, 15 ms after a negative image, and 27 ms after a non-emotional trial (see Figure 3). Nevertheless, these differences were not statistically significant.

For PE, there was also a main effect of Current Compatibility, $F(1, 47) = 17.80$, $MSE = 9.46$, $p < .001$, $\eta_p^2 = .275$, yielding a flanker effect of 1.08% ($SE = .26$). A main effect of Previous Trial Type was also significant, $F(2, 94) = 4.75$, $MSE = 14.82$, $p = .011$, $\eta_p^2 = .092$. Responses were less accurate after a negative image ($M = 3.23\%$, $SE = .44$) or a positive image ($M = 2.49\%$, $SE = .35$) than after a non-emotional trial ($M = 2.03\%$, $SE = .23$). There was no other significant effect. The sequential modulation was 0.78% after a positive image, −0.14% after a negative image, and 1.66% after a non-emotional image.

Experiment 2

The results of the ANOVAs are summarised in Table A5 in Appendix 2. Figure 3 summarizes RT and PE as well as the sequential modulations in RT and PE. The overall error rate was 4.29%, and 4.85% of all trials were discarded for the analyses.

The role of anticipation. For RT, main effects of Current Compatibility, $F(1, 47) = 63.94$, $MSE = 642.64$, $p < .001$, $\eta_p^2 = .576$, and of Previous Compatibility, $F(1, 47) = 7.54$, $MSE = 434.94$, $p = .009$, $\eta_p^2 = .138$, and their interaction, $F(1, 47) = 8.88$, $MSE = 612.23$, $p = .005$, $\eta_p^2 = .159$, were significant. The flanker effect was 21 ms overall ($Ms = 454$ vs. 475 ms for compatible and incompatible trials, respectively; $SEs = 10.35$ and 10.63), and the flanker effect was smaller after a compatible trial ($M = 28$ ms, $SE = 3.76$) than after an incompatible trial ($M = 13$ ms, $SE = 3.46$), yielding 15-ms of the sequential modulation. A main effect of Trial Type was also significant, $F(1, 47) = 20.76$, $MSE = 642.39$, $p < .001$, $\eta_p^2 = .306$. Responses were slower for an emotional trial ($M = 471$ ms, $SE = 10.59$) than for a non-emotional trial ($M = 459$ ms, $SE = 10.38$). Nevertheless, this variable did not influence sequential modulation. The sequential modulation was 14 ms for emotional trials and 16 ms for non-emotional trials.

For PE, there were main effects of Current Compatibility, $F(1, 47) = 10.56$, $MSE = 11.70$, $p = .002$, $\eta_p^2 = .184$, and of Trial Type, $F(1, 47) = 5.29$, $MSE = 9.55$, $p = .026$, $\eta_p^2 = .101$. The flanker effect was 1.12% ($Ms = 3.34\%$ vs. 4.47% for compatible and incompatible trials, respectively; $SEs = .52$ and .53). Responses were more accurate for non-emotional trials ($M = 3.55\%$, $SE = .57$) than for emotional trials ($M = 4.27\%$, $SE = .47$). No other effect was significant. The sequential modulation was 1.25% for non-emotional trials and 0.84% for emotional trials.

The role of reaction. For RT, a main effect of Current Compatibility was significant, $F(1, 47) = 28.63$, $MSE = 1423.52$, $p < .001$, $\eta_p^2 = .379$, but it depended on Previous Compatibility, $F(1, 47) = 7.41$, $MSE = 1043.67$, $p = .009$, $\eta_p^2 = .136$. The flanker effect was larger after a compatible trial ($M = 24$ ms, $SE = 3.97$) than after an incompatible trial ($M = 9$ ms, $SE = 4.30$), yielding 15 ms of the sequential modulation. A main effect of Previous Trial Type was also significant, $F(2, 94) =$

28.49, $MSE = 2602.97$, $p < .001$, $\eta_p^2 = .377$, reflecting generally longer responses after an emotional trial (Ms = 494 and 491 ms for positive and negative images, respectively; SEs = 12.14 and 12.62) than after a non-emotional trial ($M = 459$ ms, $SE = 10.39$). Nevertheless, this variable did not influence the sequential modulation. The sequential modulation was 10 ms after a positive image, 18 ms after a negative image, and 16 ms after a non-emotional trial.

For PE, there were main effects of Current Compatibility, $F(1, 47) = 7.24$, $MSE = 24.46$, $p = .010$, $\eta_p^2 = .133$, of Previous Compatibility, $F(1, 47) = 5.68$, $MSE = 19.32$, $p = .021$, $\eta_p^2 = .108$, and of Previous Trial Type, $F(2, 94) = 4.52$, $MSE = 27.02$, $p = .013$, $\eta_p^2 = .088$. The flanker effect was .98% (Ms = 3.79% vs. 4.90% for compatible and incompatible trials; SEs = .62 and .75); responses were less accurate after an incompatible trial ($M = 4.78\%$, $SE = .72$) than after a compatible trial ($M = 3.91\%$, $SE = .64$), and after a positive image ($M = 5.14\%$, $SE = .96$) or a negative image ($M = 4.35\%$, $SE = .66$) than a non-emotional trial ($M = 3.54\%$, $SE = .47$). No other effects were significant. The sequential modulation was 1.82% after a positive image, −0.61% after a negative image, and 1.25% after a non-emotional trial.

Discussion

The present experiments tested the roles of anticipating and reacting to affective pictures (Experiment 1) and emotional facial expressions (Experiment 2). The results of the two experiments were largely consistent. There was general slowing of responding and more errors when participants were cued for incoming emotional stimuli, as compared to when they were cued for the absence of emotional stimuli. Similarly, responses were generally slower and less accurate on trials that immediately followed emotional stimuli than on trials that did not. However, there was little evidence that the anticipation of or reaction to emotional stimuli influenced the sequential modulation of the flanker effect. We also reported the Bayesian analyses in Appendix 3, which tested all possible models against the best fitting model in the two experiments and provided evidence against the influence of emotional stimuli on the sequential modulation of the flanker effect. Taken together, these outcomes suggest that phasic affect has little impact on cognitive control in the flanker task.

As for facial stimuli, a recent study by Tannert and Rothermund (2020) tested the influence of facial expressions on the flanker effect. They found little indication that emotional facial expressions altered the flanker effect when the emotional stimuli appeared as flankers rather than the target. Based on their finding, the lack of the influence of facial stimuli in Experiment 2 might also be that these facial stimuli were not the target in the flanker task. Another possible reason that the present two experiments both failed to yield any indication of the influences of valence on cognitive control is that by interleaving positive and negative stimuli randomly in these experiments, participants' affective states might have been fluctuated throughout a session. Given that the influence of tonic affect (sustained emotional state) have been found more consistent than those of phasic affect in the previous studies (Dignath et al., 2020), Experiments 3 and 4 tested conditions under which emotional trials only presented either positive or negative valence throughout a session, which would produce a more sustained emotional state according to the valence of emotional stimuli.

Experiments 3 and 4

In the present two experiments, only one type of valence was used for each participant to examine whether the flanker effect and its sequential modulation depended on a more stable affective state (i.e. tonic affective state). The procedure was identical with Experiments 1 and 2 in other respects. Because the outcomes have been more consistent in the literature (e.g. Schuch & Koch, 2015; van Steenbergen et al., 2010), it was expected that the sequential modulation of the flanker effect would increase for those who were only shown negative affective pictures, but it would decrease for those who were only shown positive affective pictures.

Method

Participants

To detect a medium effect size at statistical power of .8, 44 participants were needed for an interaction between within- and between-subject factors. Two new groups of 48 participants who had not participated in the preceding experiments were recruited from the same subject pool as in Experiments 1 and 2 (Experiment 3: 35 females; mean age = 19.54, SD = 1.46, range = 18–26; Experiment 4: 31 females; mean age = 20.06, $SD = 1.60$, range = 18–26).

Apparatus, stimuli, and procedure

The present experiments were the same as Experiments 1 and 2 with the following changes: half of the participants were assigned randomly to the positive image condition in which all emotional images had a positive valence; the other half were assigned to the negative image condition in which all emotional images had a negative valence. The instructions and procedure were exactly the same as those of Experiments 1 and 2 (i.e. although participants in the positive image condition never saw negative images, the instructions still warned them that some of the images could make them feel nauseous).

Analysis

The data were analysed in the same manner as in Experiments 1 and 2, except that Group was added to the ANOVAs as a between-subject variable. Hence, to examine the role of anticipating emotional stimuli, RT and PE were now submitted to 2 (Trial Type: emotional vs. non-emotional) × 2 (Previous Compatibility: compatible vs. incompatible) × 2 (Current Compatibility: compatible vs. incompatible) × 2 (Group: positive vs. negative) ANOVAs. To examine the role of reacting to emotional stimuli, RT and PE were submitted to 2 (Previous Trial Type: emotional image vs. no image) × 2 (Previous Compatibility: compatible vs. incompatible) × 2 (Current Compatibility: compatible vs. incompatible) × 2 (Group: positive vs. negative) ANOVAs. The Bayesian ANOVAs were also carried out for RT and PE, with the same ANOVA structures as above (see Appendix 3).

Results

Experiment 3

The results of the ANOVAs are summarised in Table A6 in Appendix 2. Figure 4 summarizes RT and PE as well as the sequential modulations in RT and PE. The overall error rate was 2.92%, and 3.57% of all trials were discarded based on the same criteria as in Experiments 1 and 2.

The role of anticipation. For RT, a main effect of Group was significant, $F(1, 46) = 5.31$, $MSE = 89230.94$, $p = .026$, $\eta_p^2 = .104$. Responses were faster for the positive image group ($M = 475$ ms, $SE = 21.56$) than for the negative image group ($M = 545$ ms, $SE = 21.56$). There were also main effects of Current Compatibility, $F(1, 46) = 34.65$, $MSE = 931.53$, $p < .001$, $\eta_p^2 = .430$, and of Previous Compatibility, $F(1, 46) = 12.19$, $MSE = 785.55$, $p = .001$, $\eta_p^2 = .209$, as well as their interaction, $F(1, 46) = 31.21$, $MSE = 361.76$, $p < .001$, $\eta_p^2 = .404$. The flanker effect was 29 ms ($SE = 3.67$) after a compatible trial and 7 ms ($SE = 3.67$) after an incompatible trial. A main effect of Trial Type was also significant, $F(1, 46) = 23.50$, $MSE = 1072.50$, $p < .001$, $\eta_p^2 = .338$. Responses were slower for emotional trials ($M = 518$ ms, $SE = 15.52$) than for non-emotional trials ($M = 502$ ms, $SE = 15.15$). Trial Type interacted with Current Compatibility, $F(1, 46) = 5.77$, $MSE = 722.70$, $p = .020$, $\eta_p^2 = .111$. The flanker effect was larger for emotional trials ($M = 25$ ms, $SE = 4.55$) than for non-emotional trials ($M = 12$ ms, $SE = 3.71$). For the positive image group, the sequential modulation was 35 ms for both emotional and non-emotional trials. For the negative image group, the sequential modulation was 28 ms for non-emotional trials and was reduced to 6 ms for emotional trials. However, these differences were not significant, as indicated by the lack of an interaction among Group, Previous Compatibility, and Current Compatibility.

For PE, a main effect of Current Compatibility was significant, $F(1, 46) = 14.69$, $MSE = 7.37$, $p < .001$, $\eta_p^2 = .242$, and its interaction with Previous Compatibility was just above the significance criterion, $F(1, 46) = 4.03$, $MSE = 6.38$, $p = .051$, $\eta_p^2 = .081$. The flanker effect was 1.58% ($SE = .44$) after a compatible trial and 0.54% ($SE = .31$) after an incompatible trial. No other effects were significant.

The role of reaction. For RT, a main effect of Group was significant, $F(1, 46) = 5.20$, $MSE = 106174.44$, $p = .027$, $\eta_p^2 = .102$. Responses were faster for the negative image group ($M = 495$ ms, $SE = 23.52$) than for the positive image group ($M = 571$ ms, $SE = 23.52$). There was also a main effect of Current Compatibility, $F(1, 46) = 32.46$, $MSE = 992.56$, $p < .001$, $\eta_p^2 = .414$, and it interacted with Previous Compatibility, $F(1, 46) = 1.17$, $MSE = 856.41$, $p = .025$, $\eta_p^2 = .286$. The flanker effect was larger after a compatible trial ($M = 28$ ms, $SE = 4.57$) than after an incompatible trial ($M = 9$ ms, $SE = 3.78$). There was also a main effect of Previous Trial Type, $F(1, 46) = 66.22$, $MSE = 5708.14$, $p < .001$, $\eta_p^2 = .590$. Responses were slower after an emotional trial ($M = 565$ ms, $SE = 15.15$) than after a non-emotional trial ($M = 502$ ms, $SE = 18.80$). Previous Trial Type also interacted with Current Compatibility, $F(1, 46) = 5.52$, $MSE = 751.26$, $p = .023$, $\eta_p^2 = .107$, and with Current Compatibility and Previous

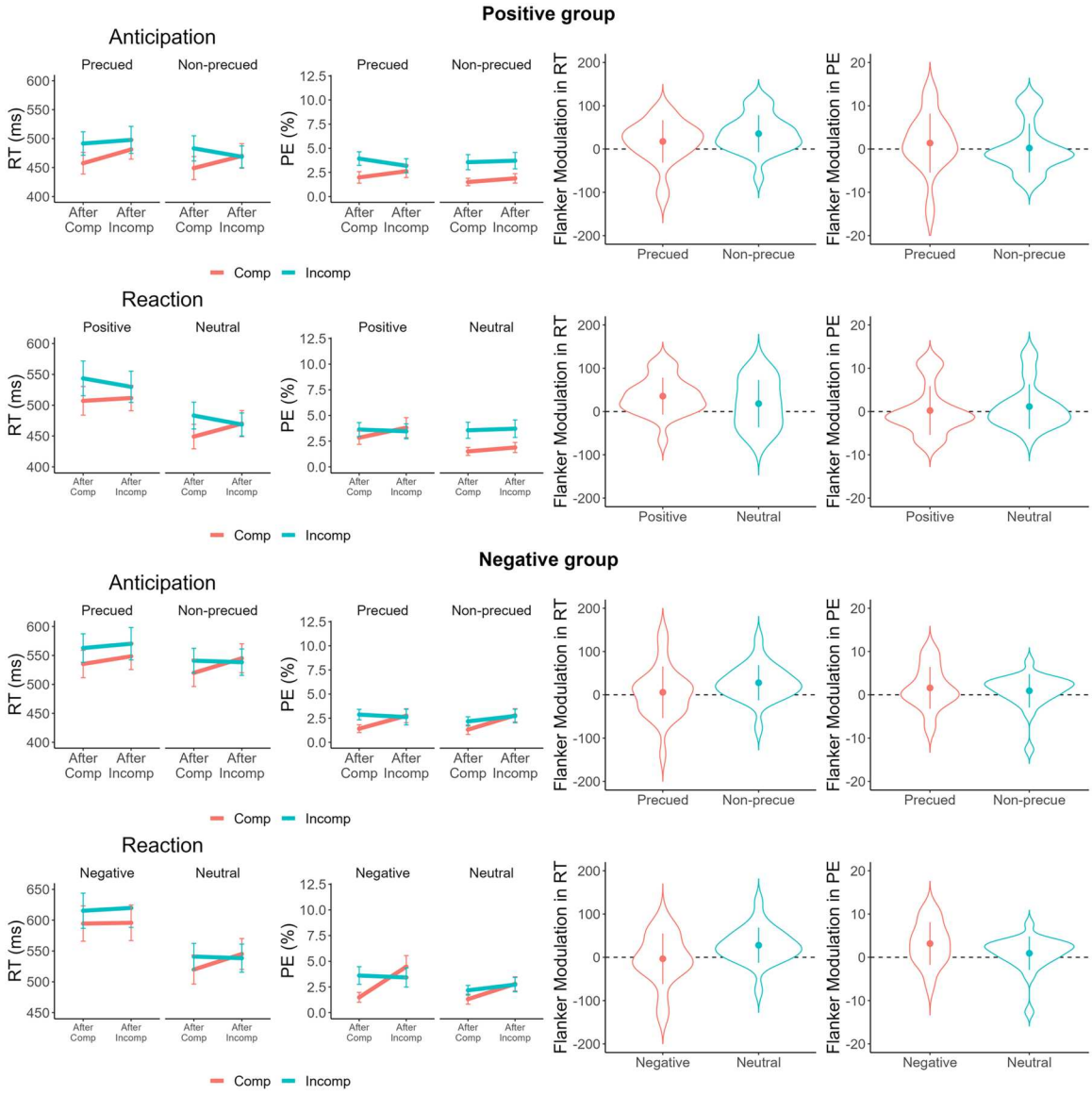

Figure 4. Mean response times (RT), percentage of error trials (PE), and the amount of sequential modulation of the flanker effect (Flanker Modulation) in RT and PE for the Positive and Negative groups of Experiment 3.

Compatibility, $F(1, 46) = 6.54$, $MSE = 539.14$, $p = .014$, $\eta_p^2 = .124$. The flanker effect was generally larger after an emotional trial ($M = 25$ ms, $SE = 3.71$) than after a non-emotional trial ($M = 12$ ms, $SE = 4.75$). Importantly, the sequential modulation was smaller after an emotional trial (*flanker effect* = 27 ms and 21 ms after compatible and incompatible trials, respectively; *SE*s = 6.16 and 6.36) than after a non-emotional trial (*flanker effect* = 28 ms and –4 ms after compatible and incompatible trials, respectively; *SE*s = 5.03 and 4.50). This dependence of the sequential modulation on Preceding Trial Type did not interact with Group.

For PE, there were main effects of Current Compatibility, $F(1, 46) = 5.84$, $MSE = 9.83$, $p = .020$, $\eta_p^2 = .113$, of Previous Compatibility, $F(1, 46) = 8.43$, $MSE = 6.78$, $p = .006$, $\eta_p^2 = .155$, and their interaction, $F(1, 46) = 7.82$, $MSE = 5.75$, $p = .008$, $\eta_p^2 = .145$. The flanker effect was 1.46% ($SE = .37$) after a compatible trial and 0.09% ($SE = .43$) after an incompatible trial. There was also a main effect of Previous Trial Type, $F(1, 46) = 4.82$, $MSE = 15.52$, $p = .033$, $\eta_p^2 = .095$.

Responses were less accurate after an emotional trial ($M = 3.34\%$, $SE = .47$) than after a non-emotional trial ($M = 2.46\%$, $SE = .30$). No other effect reached significance.

Experiment 4

The results of the ANOVAs are summarised in Table A7 in Appendix 2. Figure 5 summarizes RT and PE as well as the sequential modulations in RT and PE. The overall error rate was 3.91%, and 4.80% of all trials were discarded for the analyses.

The role of anticipation. For RT, there were main effects of Current Compatibility, $F(1, 46) = 61.63$, $MSE = 941.67$, $p < .001$, $\eta_p^2 = .573$, and of Previous Compatibility, $F(1, 46) = 14.01$, $MSE = 1213.05$, $p < .001$, $\eta_p^2 = .233$, and they interacted, $F(1, 46) = 13.51$, $MSE = 599.68$, $p < .001$, $\eta_p^2 = .227$. The flanker effect was 34 ms ($SE = 4.04$) after compatible trials

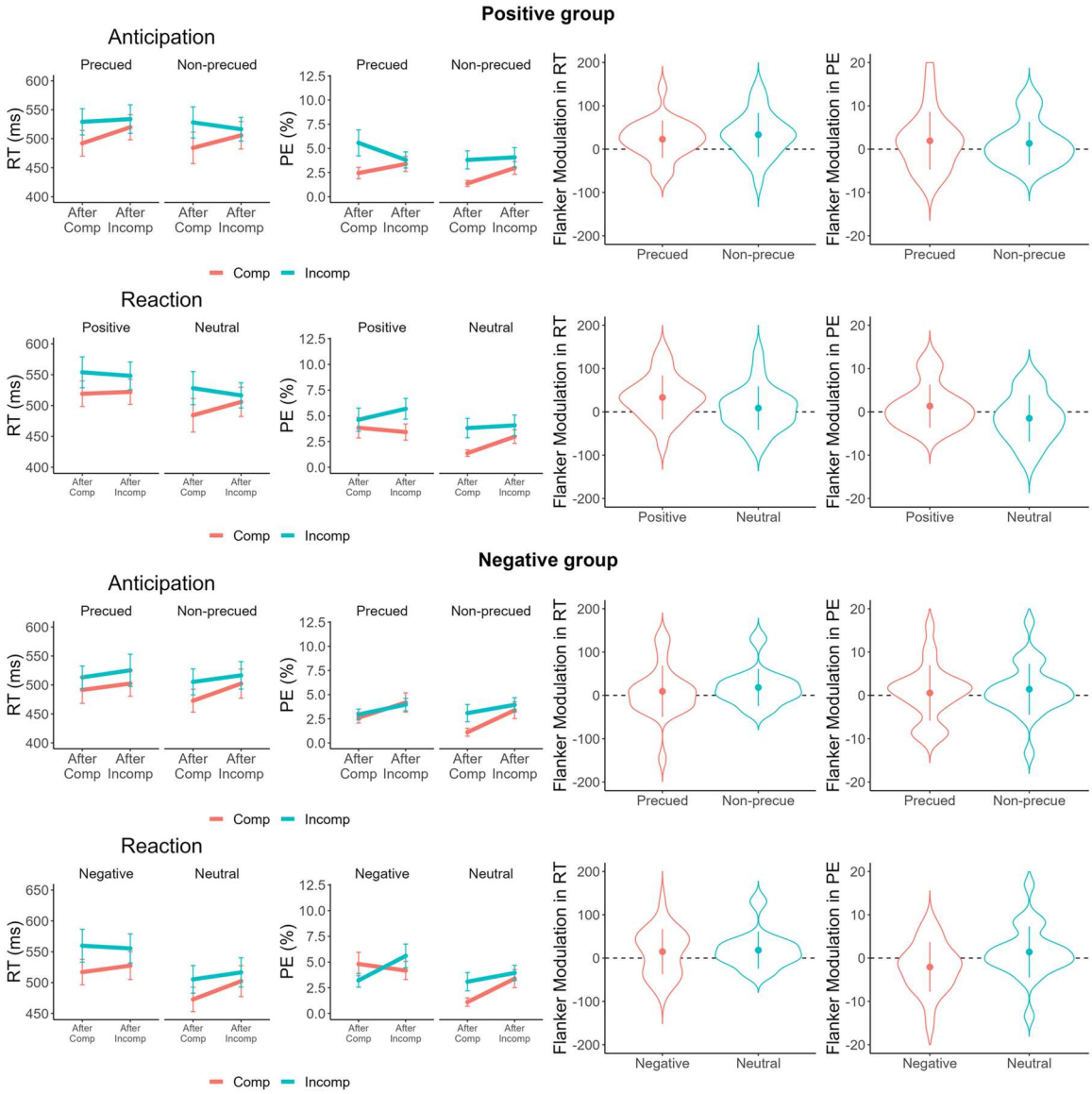

Figure 5. Mean response times (RT), percentage of error trials (PE), and the amount of sequential modulation of the flanker effect (Flanker Modulation) in RT and PE for the Positive and Negative groups of Experiment 4.

and 15 ms ($SE = 3.97$) after incompatible trials, yielding a 19-ms of the sequential modulation. A main effect of Trial Type was significant, $F(1, 46) = 9.99$, $MSE = 860.69$, $p = .003$, $\eta_p^2 = .178$. Responses were generally slower when an emotional trial was cued ($M = 513$ ms, $SE = 15.89$) than when a non-emotional trial was cued ($M = 504$ ms, $SE = 16.49$).

For PE, there were main effects of Current Compatibility, $F(1, 46) = 13.77$, $MSE = 10.35$, $p < .001$, $\eta_p^2 = .230$, and of Previous Compatibility, $F(1, 46) = 9.92$, $MSE = 6.93$, $p = .003$, $\eta_p^2 = .177$, and these factors interacted, $F(1, 46) = 7.32$, $MSE = 7.45$, $p = .010$, $\eta_p^2 = .137$. The flanker effect was 1.97% ($SE = .42$) after a compatible trial and 0.46% ($SE = .44$) after an incompatible trial. This sequential modulation was not modulated by Trial Type or Group. A main effect of Trial Type was significant, $F(1, 46) = 6.79$, $MSE = 5.90$, $p = .012$, $\eta_p^2 = .129$, reflecting less accurate responses when an emotional trial was cued ($M = 3.62\%$, $SE = 15.89$) than when a non-emotional trial was cued ($M = 2.97\%$, $SE = 16.49$). There was an interaction between Previous Compatibility and Group, $F(1, 46) = 4.79$, $MSE = 6.93$, $p = .034$, $\eta_p^2 = .094$. PEs were similar after compatible trials and after incompatible trials for the positive image group ($Ms = 3.30\%$ vs. 3.56%; $SEs = .64$) but was larger after incompatible trials ($M = 3.87\%$; $SE = .54$) than after compatible trials ($M = 2.44\%$, $SE = .54$) for the negative image group. No other effects reached significance.

The role of reaction. For RT, a main effect of Current Compatibility, $F(1, 46) = 83.42$, $MSE = 972.33$, $p < .001$, $\eta_p^2 = .645$, and its interaction with Previous Compatibility were significant, $F(1, 46) = 10.72$, $MSE = 789.97$, $p = .002$, $\eta_p^2 = .189$. The flanker effect was 38 ms ($SE = 4.45$) after a compatible trial and 20 ms ($SE = 4.11$) after an incompatible trial. However, the sequential modulation did not depend on other factors. A main effect of Previous Trial Type was also significant, $F(1, 46) = 29.88$, $MSE = 3696.62$, $p < .001$, $\eta_p^2 = .394$. Responses were faster after non-emotional trials ($M = 504$ ms, $SE = 16.49$) than after emotional trials ($M = 538$ ms, $SE = 15.61$).

For PE, there were main effects of Current Compatibility, $F(1, 46) = 10.69$, $MSE = 11.26$, $p = .002$, $\eta_p^2 = .189$, of Previous Compatibility, $F(1, 46) = 8.71$, $MSE = 9.38$, $p = .005$, $\eta_p^2 = .159$, and of Previous Trial Type, $F(1, 46) = 11.96$, $MSE = 16.92$, $p = .001$, $\eta_p^2 = .206$. These factors also interacted, $F(1, 46) = 7.58$, $MSE = 10.43$, $p = .008$, $\eta_p^2 = .141$; the sequential modulation was larger after non-emotional trials (*flanker effect* = –.40% and 1.84% after compatible and incompatible trials, respectively; *SE*s = .75 and .56) than after emotional trials (*flanker effect* = 2.21% and .83% after compatible and incompatible trials, respectively; *SE*s = .62 and .56). No other effects were significant.

Discussion

Unlike Experiments 1 and 2, Experiment 3 showed that the sequential modulation was smaller when emotional stimuli were cued on the trial (anticipation) or were presented on a preceding trial (reaction). Thus, the sequential modulation was reduced when participants anticipated or reacted to emotional stimuli. However, this reduction did not depend on whether participants saw positive or negative images. Experiment 4 also indicated some role of reacting to emotional stimuli in the sequential modulation, as the sequential modulation was reduced after emotional trials as compared to that after non-emotional trials, although the experiment provided little evidence that anticipating emotional stimuli reduced the sequential modulation. The reduced sequential modulation after emotional trials is inconsistent with some previous findings that positive and negative stimuli both *increased* the sequential modulation (Landman & van Steenbergen, 2020; Zeng et al., 2017). The researchers suggested that the influence of word meaning on the sequential modulation depended on arousal rather than valence. It was possible that arousal was responsible for the present results as well. The influence of arousal was examined more directly in Experiments 5 and 6.

Experiments 5 and 6

Recent studies using word stimuli found that the sequential modulation of the flanker effect increased for emotional word meanings as compared to neutral word meanings, regardless of the valence of the words, and it was suggested that the increase was due to the arousal component of the emotional word meanings (Landman & van Steenbergen, 2020; Zeng et al., 2017). However, their experiments did not include an explicit manipulation of arousal orthogonal to that of valence. Hence, the present experiments used affective pictures, including an additional manipulation of arousal orthogonally to that of valence. For both positive and negative groups, half of the pictures were of high arousal, and the other half were of low arousal. These pictures

were intermixed randomly. If arousal has an influence separate from that of valence, it was expected that the sequential modulation would increase for high arousal affective pictures as compared to that for low arousal affective pictures, regardless of their valence values. Experiments 5 and 6 were essentially the same as Experiment 3 in other respects, except that the exposure duration of an emotional image was reduced from 2000ms in Experiment 5–400 ms in Experiment 6. This change was made to confirm whether the reduced sequential modulation in Experiments 3 and 4 was due to the long intertrial interval after an emotional trial alone. If anticipating or reacting to emotional stimuli truly alter cognitive control, the sequential modulation would still depend on anticipated or preceding emotional stimuli, regardless of the exposure duration of emotional stimuli.

Method

Participants

New groups of 48 participants who had not participated in the preceding experiments were recruited from the same subject pool as in the preceding experiments (Experiment 5: 18 females; mean age = 20.46, *SD* = 1.65, range = 18–26; Experiment 6: 27 females; mean age = 25.40, *SD* = 9.33, range = 19–58).

Apparatus, stimuli, and procedure

The experiment was identical with Experiment 3, in which half the participants only saw positive pictures and the other half only saw negative pictures. For each group, there were 50 positive or negative pictures from the IAPS (see Table A3 in the Appendix 1). Half of the pictures were *high arousal pictures*, and the other half were *low arousal pictures*. For the positive condition, the high arousal set had an average arousal rating of 6.62, and the low arousal set had an average arousal rating of 4.11; for the negative condition, the high arousal set had an average arousal rating of 6.82, and the low arousal set had an average arousal rating of 4.61. The valence ratings for the high and low arousal sets were matched within the respective conditions; $t(48) = .56$, $p = .576$, for positive sets and, $t(48) = 1.43$, $p = .159$, for negative sets. For each group, the high and low arousal pictures were intermixed and occurred in a random order, and precues did not indicate whether the incoming affective pictures were of high or low arousal.

In addition, participants were also asked to rate their own moods during the experiment. They were presented with a two-dimensional affect grid (Russell et al., 1989) consisting of pleasure (valence; negative on the left and positive on the right) on the horizontal axis and arousal on the vertical axis (high at the top and low at the bottom), and they indicated their current mood by clicking one of the squares in the grid by a computer mouse. However, we did not report the results of these measures below because none had produced a significant effect (the data can still be found in JASP files of the corresponding experiments on the OSF page). The procedure was identical in Experiments 5 and 6 in all other respects, except that the affective pictures were presented for 2000 ms in Experiment 5 and for 400 ms in Experiment 6.

Analysis

For the role of anticipation, RT and PE were submitted to 2 (Trial Type: emotional vs. non-emotional)×2 (Previous Compatibility: compatible vs. incompatible)×2 (Current Compatibility: compatible vs. incompatible)×2 (Group: positive vs. negative) ANOVAs. Arousal was not included as a factor in these analyses because participants were not informed of the arousal for the incoming trials. For the role of reaction, RT and PE were submitted to 3 (Previous Trial Type: high arousal vs. low arousal vs. no image)×2 (Previous Compatibility: compatible vs. incompatible)×2 (Current Compatibility: compatible vs. incompatible)×2 (Group: positive vs. negative) ANOVAs. The Bayesian ANOVAs had the same ANOVA structures for the respective analyses (see Appendix 3).

Results

Experiment 5

The results of the ANOVAs are summarised in Table A8 in Appendix 2. Figure 6 summarizes RT and PE as well as the sequential modulations in RT and PE. The overall error rate was 4.19%, and 5.00% of all trials were discarded before the analyses.

The role of anticipation. For RT, main effects of Current Compatibility, $F(1, 46) = 38.33$, $MSE = 622.06$, $p < .001$, $\eta_p^2 = .455$, and of Previous Compatibility, $F(1, 46) = 27.15$, $MSE = 574.94$, $p < .001$, $\eta_p^2 = .371$, were significant, and these two variables interacted, $F(1, 46) = 15.75$, $MSE = 683.04$, $p < .001$, $\eta_p^2 = .255$. The flanker effect was 26 ms ($SE = 4.22$) after compatible

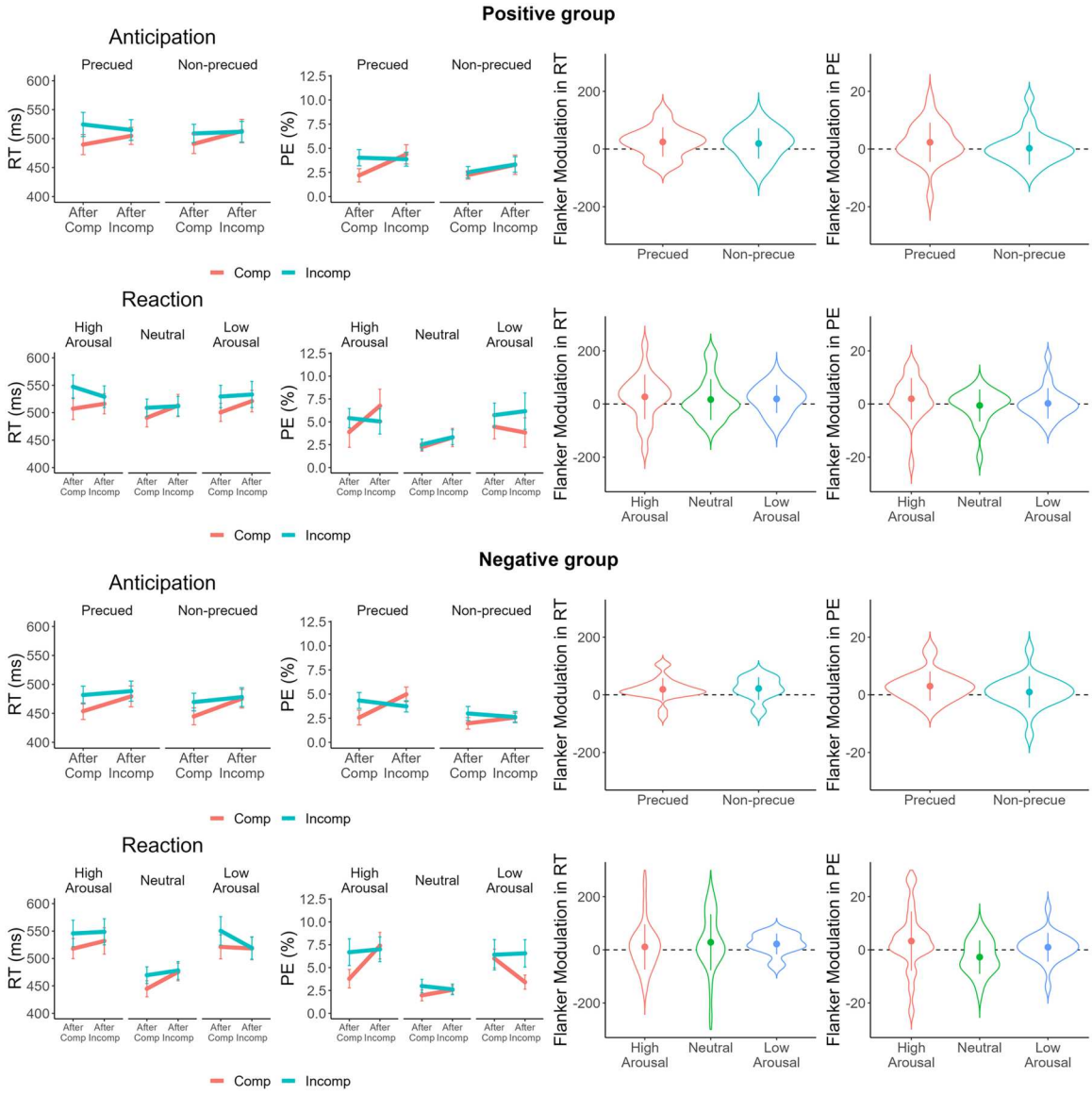

Figure 6. Mean response times (RT), percentage of error trials (PE), and the amount of sequential modulation of the flanker effect (Flanker Modulation) in RT and PE for the Positive and Negative groups of Experiment 5.

trials and 5 ms ($SE = 3.06$) after incompatible trials. Previous Compatibility also interacted with Group, $F(1, 46) = 4.30$, $MSE = 574.94$, $p = .044$, $\eta_p^2 = .085$. Responses were 8 ms ($SE = 3.46$) faster after compatible trials than after incompatible trials for the positive image group, and 18 ms ($SE = 3.46$) faster after compatible trials than after incompatible trials for the negative image group. The main effect of Trial Type was only marginal, $F(1, 46) = 3.94$, $MSE = 747.89$, $p = .053$, $\eta_p^2 = .079$, but responses tended to be slower for emotional trials ($M = 492$ ms, $SE = 11.60$) than for non-emotional trials ($M = 487$ ms, $SE = 11.39$), as in the preceding experiments. Unlike Experiment 3, the results did not show the influence of Trial Type on the sequential modulation of the flanker effect.

For PE, a main effect of Previous Compatibility was significant, $F(1, 46) = 6.58$, $MSE = 7.93$, $p = .014$, $\eta_p^2 = .125$, but not of Current Compatibility; these variables still interacted, $F(1, 46) = 6.09$, $MSE = 10.67$, $p = .017$, $\eta_p^2 = .117$. The flanker effect was 1.23%

(*SE* = .42) after compatible trials and –0.42% (*SE* = .43) after incompatible trials. A main effect of Trial Type was significant, $F(1, 46) = 12.00$, $MSE = 9.16$, $p = .001$, $\eta_p^2 = .207$. Responses were more accurate for non-emotional trials (*M* = 2.69%, *SE* = .33) than for emotional trials (*M* = 3.76%, *SE* = .44). The 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility did not reach significance.

The role of reaction. For RT, a main effect of Current Compatibility was significant, $F(1, 46) = 48.24$, $MSE = 934.99$, $p < .001$, $\eta_p^2 = .512$, and it interacted with Previous Compatibility, $F(1, 46) = 8.76$, $MSE = 1770.53$, $p = .005$, $\eta_p^2 = .160$. The flanker effect was 28 ms (*SE* = 4.19) after compatible trials and 7 ms (*SE* = 4.48) after incompatible trials. There was also a main effect of Previous Trial Type, $F(2, 92) = 26.85$, $MSE = 4032.05$, $p < .001$, $\eta_p^2 = .369$; responses were slower after high arousal (*M* = 531 ms, *SE* = 14.19) and low arousal (*M* = 524 ms, *SE* = 14.12) trials than after non-emotional trials (*M* = 487 ms, *SE* = 11.39). Previous Trial Type also interacted with Group, $F(1, 46) = 9.15$, $MSE = 4032.05$, $p < .001$, $\eta_p^2 = .166$. The differences between the two emotional trials and non-emotional trials were larger for the negative image group (*M*s = 536 and 527 ms for high and low arousal trials vs. 467 ms for non-emotional trials; *SE*s = 20.07, 19.97, and 16.11) than for the positive image group (*M*s = 525 and 521 ms for high and low arousal trials vs. 506 ms for non-emotional trials; *SE*s = 20.07, 19.97, and 16.11). Previous Trial Type also interacted with Previous Compatibility, $F(2, 92) = 3.70$, $MSE = 1217.74$, $p = .028$, $\eta_p^2 = .075$, and these factors also interacted with Group, $F(2, 92) = 5.12$, $MSE = 1217.74$, $p = .008$, $\eta_p^2 = .100$. For the positive image group, the differences in RT between trials following compatible and incompatible trials were 13 ms, 12 ms, and –5 ms, after non-emotional, low arousal, and high arousal trials, respectively (*SE*s = 5.36, 8.01, and 7.45). For the negative image group, they were 20 ms, –17 ms, and 8 ms, after non-emotional, low arousal, and high arousal trials, respectively (*SE*s = 5.36, 8.01, and 7.45). Despite of these influences of Previous Trial Type, it did not influence the sequential modulation of the flanker effect.

For PE, there were main effects of Current Compatibility, $F(1, 46) = 4.09$, $MSE = 28.90$, $p = .049$, $\eta_p^2 = .082$, and of Previous Trial Type, $F(1, 46) = 17.53$, $MSE = 30.09$, $p < .001$, $\eta_p^2 = .276$, reflecting the overall flanker effect of .9% (*SE* = .45) and more accurate responses after non-emotional trials (*M* = 2.69%, *SE* = .33) than after high arousal or low arousal trials (*M* = 5.75% and 5.32%, respectively; *SE*s = .78 and .80). Current Compatibility interacted with Previous Compatibility and Previous Trial Type, $F(1, 46) = 3.75$, $MSE = 21.18$, $p = .027$, $\eta_p^2 = .075$. The sequential modulation was larger after high arousal trials (*flanker effect* = 2.20% and –1.05% after compatible and incompatible trials, respectively; *SE*s = 1.19 and 1.01) than after low arousal trials (*flanker effect* = .85% and 2.74% after compatible and incompatible trials, respectively; *SE*s = .94 and 1.30) or after non-emotional trials (*flanker effect* = .66% and .04% after compatible and incompatible trials, respectively; *SE*s = .61 and .41).

Experiment 6

The results of the ANOVAs are summarised in Table A9 in Appendix 2. Figure 7 summarizes RT and PE as well as the sequential modulations in RT and PE. The overall error rate was 4.82%, and 5.23% of all trials were discarded before the analyses.

The role of anticipation. For RT, main effects of Current Compatibility, $F(1, 46) = 68.83$, $MSE = 568.30$, $p < .001$, $\eta_p^2 = .599$, and of Previous Compatibility, $F(1, 46) = 8.27$, $MSE = 827.37$, $p = .006$, $\eta_p^2 = .152$, were significant, and their interaction was only marginal, $F(1, 46) = 3.89$, $MSE = 560.58$, $p = .055$, $\eta_p^2 = .078$. The flanker effect was 25 ms (*SE* = 3.26) after compatible trials and 16 ms (*SE* = 3.59) after incompatible trials. There was also a main effect of Trial Type, $F(1, 46) = 8.88$, $MSE = 593.09$, $p = .005$, $\eta_p^2 = .162$. Responses were still slower when emotional trials were precued (*M* = 488 ms, *SE* = 12.98) than when non-emotional trials were precued (*M* = 480 ms, *SE* = 12.73). No other effects were significant.

For PE, a main effect of Current Compatibility, $F(1, 46) = 9.31$, $MSE = 13.25$, $p = .004$, $\eta_p^2 = .168$, and its interaction with Previous Compatibility, $F(1, 46) = 10.55$, $MSE = 9.58$, $p = .002$, $\eta_p^2 = .187$, was significant. The flanker effect was 2.16% (*SE* = .46) after compatible trials and .11% (*SE* = .52) after incompatible trials. No other effects were significant.

The role of reaction. For RT, there were main effects of Current Compatibility, $F(1, 46) = 46.21$, $MSE = 1099.59$, $p < .001$, $\eta_p^2 = .501$, and of Previous Compatibility, $F(1, 46) = 15.49$, $MSE = 713.20$, $p < .001$, $\eta_p^2 = .252$, but their interaction was no longer significant, although the flanker effect was 24 ms (*SE* = 4.33) after compatible trials and 14 ms (*SE* = 3.61) after incompatible trials. No other effects were significant.

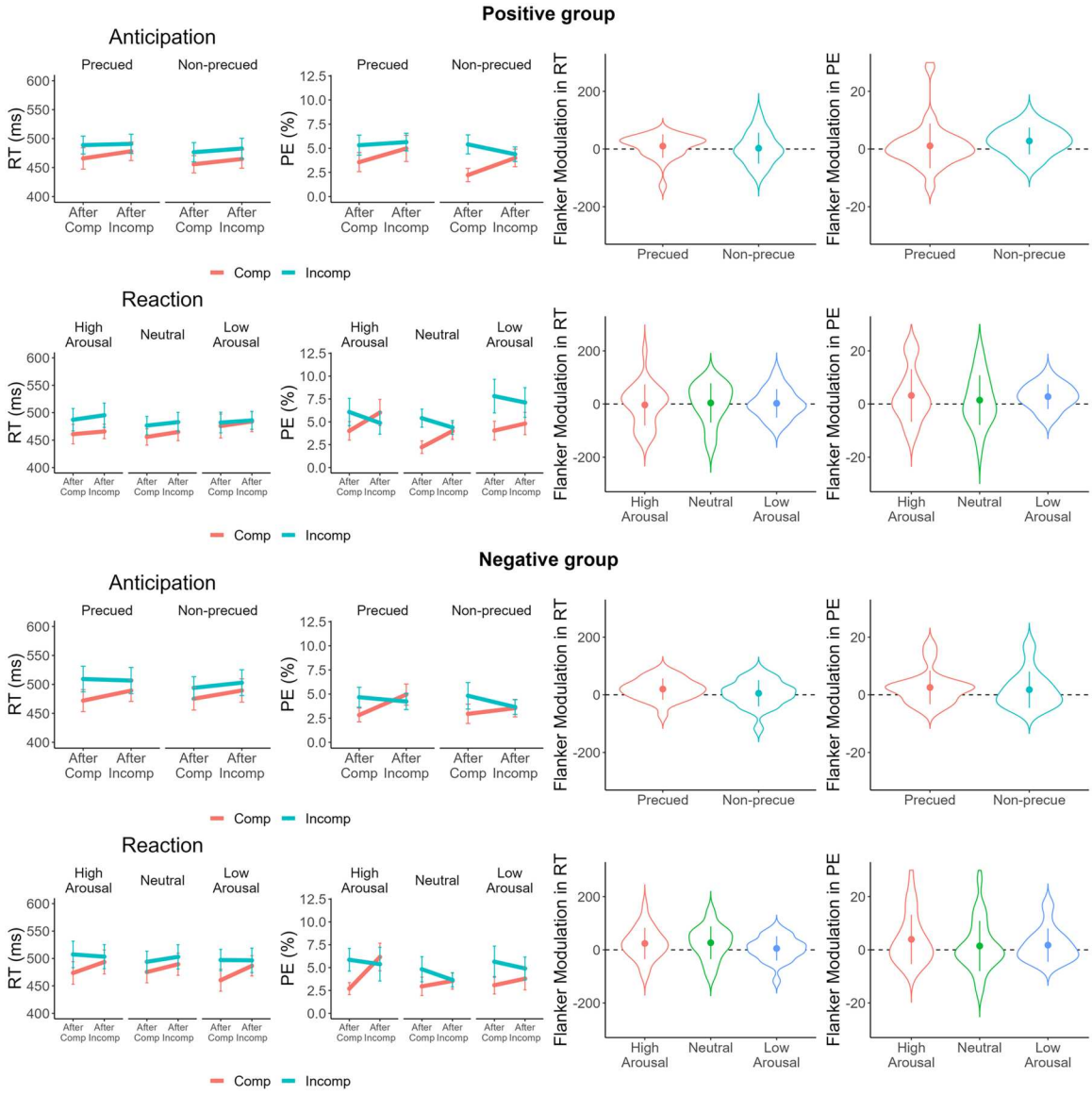

Figure 7. Mean response times (RT), percentage of error trials (PE), and the amount of sequential modulation of the flanker effect (Flanker Modulation) in RT and PE for the Positive and Negative groups of Experiment 6.

For PE, there was a main effect of Current Compatibility, $F(1, 46) = 26.08$, $MSE = 13.26$, $p < .001$, $\eta_p^2 = .362$, and this interacted with Previous Compatibility, $F(1, 46) = 8.94$, $MSE = 23.87$, $p = .004$, $\eta_p^2 = .163$. The flanker effect was 2.77% ($SE = .55$) after compatible trials and .33% ($SE = .47$) after incompatible trials. A main effect of Previous Trial Type was also significant, $F(1, 46) = 3.68$, $MSE = 28.08$, $p = .029$, $\eta_p^2 = .074$, showing less accurate responses after high arousal ($M = 5.14\%$, $SE = .77$) and low arousal ($M = 5.15\%$, $SE = .79$) trials than after non-emotional trials ($M = 3.87\%$, $SE = .54$). No other effects were significant.

Discussion

The present experiments explicitly manipulated the arousal component of affective pictures and examined whether it influenced the sequential modulation of the flanker effect. However, these experiments did not provide robust evidence that anticipating or

reacting to affective pictures influenced the sequential modulation of the flanker effect. In Experiment 5, PE showed a larger sequential modulation when emotional trials were precued than when non-emotional trials were precued, suggesting some role of anticipating affective pictures. Furthermore, the sequential modulation was also larger when the preceding trial was of high arousal than when it was of low arousal. Some caution is required in interpreting these results as they were found only in PE but not in RT, but the results are still consistent with the recent findings where emotional or non-emotional word meanings were task-irrelevant in the flanker task (Landman & van Steenbergen, 2020; Zeng et al., 2017). Nevertheless, Experiment 6 did not reproduce these outcomes. Overall, these experiments provided some indications that anticipating or reacting to emotional stimuli could influence the sequential modulation of the flanker effect, but their influences appear quite elusive.

General discussion

The flanker task has been used to investigate the emotional basis of cognitive control in recent studies (e.g. Kanske & Kotz, 2010; van Steenbergen et al., 2010; Zeng et al., 2017), but the findings from the previous studies are mixed (Dignath et al., 2020; Zhang et al., 2023). Some found that emotional stimuli increased the sequential modulation of the flanker effect regardless of their valence (Landman & van Steenbergen, 2020; Zeng et al., 2017), and others found that negative moods increased the sequential modulation as compared to positive moods (Schuch & Koch, 2015; van Steenbergen et al., 2010). Some studies also reported a smaller flanker effect with negative stimuli with words (Kanske & Kotz, 2010) or faces (Fenske & Eastwood, 2003; Grose-Fifer et al., 2013), but others found no valence-specific effects on the flanker effect with facial expressions either (Cañadas et al., 2016; Mueller & Kuchinke, 2016; Zhang et al., 2019). Given the diversity of the procedure and stimuli used in these studies, it is difficult to determine whether there is a real influence of affective processes on cognitive control in the flanker task or other conflict tasks (see Zhang et al., 2023, for a meta-analysis). Therefore, the present study carried out six experiments that used the same flanker task but with different manipulations of the emotional factors across them. As expected, the flanker effect was robust across all experiments, especially in RT, which ranges between 20 and 30 ms overall, and the flanker effect also depended on the compatibility on a preceding trial, yielding the sequential modulation in all experiments. Nevertheless, the influences of emotional stimuli on the flanker effect or its sequential modulation were rather elusive and often inconsistent with previous findings.

In Experiments 1 and 2, participants were presented with affective pictures from the IAPS or facial expressions (happy or fearful) on emotional trials that occurred in a third of the trials. Positive and negative images were intermixed in a random order in these experiments. Hence, these experiments focused on the phasic (i.e. transient) influences of emotional pictures on cognitive control in the flanker task. When an emotional trial was precued, responses became slower and less accurate than when a non-emotional trial was precued, reflecting the anticipation of an emotional image. However, there was little influence of anticipating an emotional image on the flanker effect or its sequential modulation. Responses also tended to be slower and less accurate after an emotional trial. Slower responses after emotional stimuli (than those after neutral stimuli) were also reported in a previous study (Landman & van Steenbergen, 2020), and this finding was robust across the six experiments in the present study. However, Experiments 1 and 2 did not reveal any influence of anticipating or reacting to emotional stimuli on cognitive control. The lack of the effect of phasic affect is consistent with Dignath et al.'s (2017) finding in the Simon task, for which affective pictures did not influence the sequential modulation of the Simon effect.

In Experiments 3 and 4, the same valence-laden images as in Experiments 1 and 2 were used, but positive and negative images were separated between different groups of participants. Hence, each participant only encountered either positive or negative stimuli, which excluded a possible carrying over influences from the emotional stimuli of the opposite affect. It was also expected that having either of the emotional stimulus types would result in a sustained affective state (i.e. tonic affect) as opposed to a transient one (phasic affect) in Experiments 1 and 2. With affective pictures, Experiment 3 yielded a larger flanker effect when an emotional trial was precued or performed previously. These outcomes appear to reflect a smaller sequential modulation (i.e. small reduction of the flanker effect after incompatible

trials) for these emotional trials. These results were also suggested in Experiment 4 that used facial expressions. Interestingly, however, these outcomes did not depend on whether participants saw positive or negative images. Recent studies also found influences of emotional words on the sequential modulation that did not depend on the valence of stimuli (Landman & van Steenbergen, 2020; Zeng et al., 2017), but their results showed a *greater* sequential modulation with emotional words than with neutral words, opposite to what Experiments 3 and 4 of the present study showed.

Although the direction of the influences of emotional stimuli was opposite to what the previous studies found, Experiments 5 and 6 tested whether the results of Experiments 3 and 4 could be attributed to higher arousal caused by emotional stimuli as previously proposed (Landman & van Steenbergen, 2020). These experiments, thus, manipulated the arousal and valence of affective pictures from the IAPS orthogonally. The influences of affective pictures on the overall responses were also obtained in these experiments, but there was no consistent pattern indicating the influences of affective images on the flanker effect or its sequential modulation. In Experiment 5, there was an increase in the sequential modulation after high arousal trials, but this was obtained only in PE but not in RT, which partially supported the proposal that arousal does influence cognitive adjustment reflected by the sequential modulation. However, the results were not replicated in Experiment 6 for which affective pictures were only shown for a shorter duration (400 ms, as opposed to 2000ms in Experiment 5).

Overall, the results of the present study suggest that the influences of affective pictures do appear in some conditions (Experiments 3 and 4), but subtle changes in the procedure can eliminate the influences (Experiments 1 and 2, and 6) or reverse the direction of the influence (Experiment 5), even with the same flanker task across the experiments. These results would resist simple explanations within a single theoretical framework. This may be due to the multi-faceted nature of affective processing, or there may be large individual differences that cannot be accounted for by a general theory. More fine-grained analyses might allow disentangling factors influencing the manifestations of affective influences on cognitive control, and further scrutiny of methodological issues is also required. Therefore, we conclude that the results of the present study pose challenges to theories of cognitive control that assumes a central role of affective processes in regulating cognitive processes.

What does it take for affective stimuli to influence cognitive control?

As in the present study, previous studies of affective influences on cognitive control used affective pictures presented before or after trials (e.g. Braem et al., 2013; Dreisbach & Goschke, 2006), whereas others used affective words (e.g. Kanske & Kotz, 2010; Zeng et al., 2017). More recently, Bognar et al. (2023) argued that the influences of phasic affect can be sensitive to "cognitive domain switching", which is defined roughly as a "drastic change in cognitive domains" between processing emotional stimuli and performing the main cognitive task such as the current flanker task. For example, they suggested that Dignath et al. (2017) failed to observe the influence of phasic affect on the sequential modulation in the Simon task because there was a cognitive domain switch between processing affective pictures and performing the Simon trials. To minimise such a cognitive domain switch, they suggested to use emotional stimuli that are similar to those used in the main cognitive task (e.g. emotional words with the flanker task with letter stimuli). In their experiments, Bognar et al. also failed to obtain an influence of affective words on the flanker effect in a letter-version of the flanker task, although their exploratory analysis still found its sequential modulation increased after negative words (see their supplementary analysis). Hence, their results are difficult to interpret as they provided contradicting results. Whether a cognitive domain switch as defined by Bognar et al. is responsible for the mixed findings in the previous studies of sequential modulation is still to be confirmed in future investigations.

It has also been suggested that the influence of affective stimuli would be more robust when the affective stimuli were part of the target stimuli to which participants respond to (Dignath et al., 2020). The same conclusion was reached by Tannert and Rothermund (2020) who used facial stimuli in the flanker task. Duggirala et al. (2022) suggested that emotional salience rather than valence is more important for affective influences on conflict processing. In the present study, emotional stimuli were (visually) salient as they occupied a large portion of the display. Although participants were asked not to

look away from the images as they were presented during trials, nothing prevented them from doing so. Following Tannert and Rothermund's suggestion, it may be that processing affective values of these stimuli might not be as automatic or obligatory as it may seem from previous findings. The elusive effects of emotional stimuli might be due partly to this procedural limitation, and it might be a contributing factor for the mixed results of phasic affect in the previous studies.

Furthermore, several recent studies suggested that when emotional stimuli are anticipated and known to distract their attention in advance, participants could suppress or avoid processing emotional stimuli proactively (e.g. Cohen et al., 2011; Grützmann et al., 2022) even at the perceptual level (Flaisch et al., 2019). Many studies have found that threat-related stimuli, such as fearful faces (Berggren & Derakshan, 2013), weapons (Zsido et al., 2020), or spiders (Yamaguchi & Harwood, 2017), capture visual attention. Xu et al. (2023) also found that emotional stimuli (fearful faces) captured attention and distracted visual search when they appeared as one of the distractors in a singleton search task (when the search target was different in skin-tone from distractors). However, in a feature search task (when the search target could not be identified by a single feature), target search was faster when the emotional distractor was presented as a singleton than when it was absent, which could happen if the emotional distractor was suppressed perceptually. Nevertheless, this suppression was obtained only when the identity of the emotional distractor was known in advance but not when the identity of the emotional distractor could change over trials. Similarly, Grimshaw et al. (2018) presented positive and negative affective pictures from the IAPS during a visual (singleton) search and found that distraction from these emotional stimuli were reduced when they occurred more frequently. The researchers suggested that frequent presentations encouraged a proactive mode, allowing participants to exert stronger control over the emotional stimuli. Other researchers also proposed that a stronger control mode either reduces or eliminates the influences of emotional stimuli that could otherwise impair task performance (e.g. Cohen et al., 2011; Grützmann et al., 2019; Keha et al., 2024; Straub et al., 2020).

Makovski and Chajut (2021) also investigated whether people prepared for incoming threat-related stimuli when the occurrence of these stimuli were known in advance. They presented threat-related stimuli during the retention interval of a visual short-term memory task (change detection task) and presented a probe to be responded to in a subset of these trials. Unlike Xu et al.'s and Grimshaw et al.'s studies, their results indicated that participants did not suppress expected threatening stimuli. Hence, suppression of emotional stimuli is circumstantial, possibly depending on a multitude of factors (e.g. known distractor identity, demanding target processing, and high frequency of occurrence), and does not appear to occur automatically even when people expect them. Yet, one could still question that participants were also able to suppress emotional stimuli in the present series of experiments. These considerations would mean that merely anticipating positive or negative images is not sufficient to influence cognitive control, in contrast to the anticipatory effect of reward on the sequential modulation of the flanker effect that has been found in previous studies (e.g. Yamaguchi & Nishimura, 2019). Procedures that ensure encoding emotional contents of the image (e.g. including catch trials) might be necessary to obtain a robust affective influence on the flanker effect. A recent meta-analysis on emotional modulations of the flanker and similar effects (Simon and Stroop effects) also indicated that influences of emotional stimuli are more robust when these stimuli are an integral part of the task being performed (Zhang et al., 2023). Hence, future research that aims to test the influence of emotional stimuli on cognitive control should integrate attention check into the design, such as a dot-probe task on a subset of trials as in Makovski and Chajut's (2021) study, to examine emotional stimuli are encoded during a cognitive control task.

As a final remark, the present study focused on the sequential modulation of the flanker effect as an overt manifestation of the underlying cognitive control process, and the dual-process theory has played a central role in this conceptualisation (Botvinick et al., 2001; Braver, 2012). However, researchers have proposed other potential mechanisms that could also contribute to the sequential modulation observed in the flanker task or other similar tasks, and these mechanisms could operate simultaneously and determine the observed sequential modulation in concert (Egner, 2014). In fact, while the dual-process theory would predict that positive stimuli would counter the aversive signal from preceding conflict and *reduce* the sequential modulation, an associative

learning theory (Verguts & Notebaert, 2009) would predict that positive "reward" strengthens the association between stimulus and response and could *amplify* the sequential modulation, especially when rewards are contingent on one's performance (Braem et al., 2012). These confounding mechanisms of the sequential modulation produce opposing affective influences and may cancel out each other. Furthermore, there have been recent efforts to develop an integrated framework to account for a range of different cognitive paradigms based on episodic binding and retrieval (Frings et al., 2020; Schmidt et al., 2016). A study found that episodic binding and retrieval are independent of affective modulations (Palmar & Rothermund, 2024), which agrees with the lack of a consistent effect of affective stimuli in the present study. Teasing part these potential mechanisms of cognitive control is an ongoing effort (e.g. Braem et al., 2019) and poses another methodological challenge to understand affective influences on cognitive control. Without overcoming these methodological challenges and further clarifications of the elusive nature of the affective influences in the flanker task and other cognitive tasks, theorizing the emotional-basis of cognitive control requires great caution.

Notes

1. We chose to adopt a medium effect size for the power analysis based on the findings of Yamaguchi and Nishimura (2019, Experiment 2), based on which the present study was designed and in which the target effect yielded medium to large effect sizes.
2. For each image, the magnitude of valence was calculated as the absolute distance from the middle value of the rating (= 5). For example, if a picture is rated 3 for its valence, the valence magnitude is $2 = |3 - 5|$.
3. Lee and Wagenmakers (2013) considered BF < P3 anecdotal evidence, BF < 10 moderate evidence, and BF < 30 strong evidence.

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Data availability statement

For the purpose of open access, the author has applied a Creative Commons Attribution (CC-BY) license to any Author Accepted Manuscript version arising. The experimental data, programmes, analysis scripts, and preprints can be found in the OSF project page (https://osf.io/y54pu/). We thank David Dignath, Klaus Rothermund, and an anonymous reviewer, for their valuable comments on earlier drafts.

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Appendices

Appendix 1

Affective pictures and facial expressions used in Experiments 1–6.

Table A1. Arousal and valence ratings of the positive and negative images used in Experiments 1 and 3 (IAPS = International Affective Picture System; Lang et al., 2008).

Group	IAPS Number	Valence Rating	Arousal Rating	Valence Magnitude
Positive	1463	7.45	4.79	2.45
	1710	8.34	5.41	3.34
	1811	7.62	5.12	2.62
	2045	7.87	5.47	2.87
	2058	7.91	5.09	2.91
	2209	7.64	5.59	2.64
	2216	7.57	5.83	2.57
	2345	7.41	5.42	2.41
	2347	7.83	5.56	2.83
	4626	7.60	5.78	2.60
	5480	7.53	5.48	2.53
	5825	8.03	5.46	3.03
	5830	8.00	4.92	3.00
	5833	8.22	5.71	3.22
	5910	7.80	5.59	2.80
	7270	7.53	5.76	2.53
	7330	7.69	5.14	2.69
	7405	7.38	6.28	2.38
	7502	7.75	5.91	2.75
	8210	7.53	5.94	2.53
	8380	7.56	5.74	2.56
	8420	7.76	5.56	2.76
	8496	7.58	5.79	2.58
	8499	7.63	6.07	2.63
	8502	7.51	5.78	2.51
Negative	2205	1.95	4.53	3.05
	2345.1	2.26	5.50	2.74
	2710	2.52	5.46	2.48
	2800	1.78	5.49	3.22
	3051	2.30	5.62	2.70
	3180	1.92	5.77	3.08
	3191	1.95	5.95	3.05
	3215	2.51	5.44	2.49
	3550	2.54	5.92	2.46
	6243	2.33	5.99	2.67
	6838	2.45	5.80	2.55
	9043	2.52	5.50	2.48
	9075	1.66	6.04	3.34
	9140	2.19	5.38	2.81
	9181	2.26	5.39	2.74
	9185	1.97	5.65	3.03
	9220	2.06	4.00	2.94
	9253	2.00	5.53	3.00
	9295	2.39	5.11	2.61
	9301	2.26	5.28	2.74
	9322	2.24	5.73	2.76
	9420	2.31	5.69	2.69
	9571	1.96	5.64	3.04
	9900	2.46	5.58	2.54
	9902	2.33	6.00	2.67

Table A2. Face stimuli used in Experiments 2 and 4 (CFD = Chicago Face Database; Ma et al., 2015; W = White; B = Black; F = Female; M = Male).

CFD ID	Race	Gender	Perceived Age	Fearfulness	Happiness	Trustworthiness	Attractiveness
Set A							
WF-002	W	F	30.16	2.26	1.70	3.17	1.61
WF-006	W	F	24.34	2.97	2.17	3.61	3.48
WF-008	W	F	30.21	2.05	2.95	3.88	2.73
WF-009	W	F	23.31	2.96	2.21	3.44	3.19
WF-011	W	F	24.04	1.95	2.43	3.70	4.13
WF-014	W	F	36.10	1.85	3.29	3.76	3.28
WF-016	W	F	25.41	2.04	2.63	3.24	3.71
WF-018	W	F	33.87	3.90	1.89	3.38	3.69
WF-019	W	F	28.35	2.26	1.73	3.11	2.93
WF-020	W	F	26.02	2.51	2.58	3.62	3.33
WF-022	W	F	19.91	2.08	3.21	4.16	5.09
WF-024	W	F	23.94	1.94	2.57	3.73	4.76
WF-028	W	F	27.25	2.51	2.01	3.10	2.48
WF-029	W	F	24.36	1.95	1.72	3.22	4.22
WF-033	W	F	32.04	1.96	2.80	3.86	3.39
WF-035	W	F	24.76	2.07	2.41	3.54	3.39
WF-037	W	F	23.50	1.93	2.10	3.30	2.69
WF-038	W	F	28.72	2.02	2.92	3.74	3.32
WM-001	W	M	16.94	2.55	1.97	3.22	2.65
WM-002	W	M	30.43	2.04	2.01	2.98	2.51
WM-010	W	M	27.40	2.53	1.49	2.46	2.28
WM-011	W	M	30.99	2.05	1.92	3.06	3.17
WM-014	W	M	33.71	2.08	3.25	3.81	3.48
WM-016	W	M	30.40	2.10	2.12	3.08	3.26
WM-017	W	M	23.59	2.35	2.34	2.81	2.36
WM-018	W	M	36.16	1.89	2.40	3.39	2.70
WM-019	W	M	25.11	2.26	1.75	2.70	2.28
WM-023	W	M	37.59	1.89	3.39	3.81	2.87
WM-025	W	M	21.12	2.23	2.82	3.49	2.78
WM-026	W	M	25.69	2.01	2.53	3.17	3.09
WM-028	W	M	24.93	2.53	2.64	3.55	3.20
WM-029	W	M	28.59	1.89	2.67	3.70	4.59
WM-031	W	M	21.74	2.29	2.47	3.39	3.05
WM-032	W	M	25.49	1.82	3.69	3.56	2.64
WM-036	W	M	22.66	2.08	1.91	2.83	2.77
WM-039	W	M	19.24	2.12	1.95	3.02	2.43
Set B							
WF-001	W	F	24.95	2.25	2.07	3.30	3.11
WF-003	W	F	26.71	2.03	3.33	4.05	4.89
WF-005	W	F	22.39	1.91	2.34	3.75	3.03
WF-007	W	F	21.80	1.78	3.24	3.78	2.89
WF-010	W	F	26.25	1.93	2.22	3.58	2.01
WF-012	W	F	23.18	2.54	2.47	3.80	4.66
WF-013	W	F	26.42	1.71	3.60	4.01	3.57
WF-015	W	F	24.21	1.93	2.69	3.88	4.65
WF-017	W	F	23.30	2.17	2.79	3.51	3.28
WF-021	W	F	25.69	2.49	2.21	3.49	3.93
WF-023	W	F	32.74	2.22	3.05	3.57	2.74
WF-025	W	F	28.11	2.78	2.20	3.32	4.30
WF-026	W	F	37.23	2.60	1.94	3.20	1.72
WF-027	W	F	21.29	1.60	3.08	3.96	4.69
WF-030	W	F	24.18	2.55	2.28	3.80	2.73
WF-031	W	F	23.24	2.17	2.45	3.73	4.12
WF-034	W	F	28.12	2.14	2.33	3.39	2.18
WF-036	W	F	22.64	2.82	1.99	3.37	2.90
WM-003	W	M	23.35	1.99	2.54	3.58	3.68
WM-004	W	M	25.82	1.80	2.63	3.56	4.66
WM-006	W	M	25.65	1.97	2.75	3.43	3.51
WM-009	W	M	23.70	2.12	2.26	3.51	4.08
WM-012	W	M	32.14	2.48	1.92	3.36	2.84
WM-013	W	M	32.38	2.49	2.12	3.21	2.76

(*Continued*)

Table A2. Continued.

CFD ID	Race	Gender	Perceived Age	Fearfulness	Happiness	Trustworthiness	Attractiveness
WM-015	W	M	23.37	2.13	2.17	3.31	3.51
WM-020	W	M	34.97	2.42	2.24	3.07	2.69
WM-021	W	M	29.12	2.18	1.98	3.00	2.66
WM-022	W	M	29.06	1.97	2.00	3.01	2.89
WM-024	W	M	20.82	2.43	2.89	3.78	3.65
WM-033	W	M	26.59	1.73	2.51	3.58	3.85
WM-034	W	M	23.22	2.16	2.31	3.18	2.70
WM-035	W	M	20.71	2.59	1.90	2.76	2.16
WM-037	W	M	17.55	2.17	1.88	3.13	2.43
WM-038	W	M	25.52	1.93	1.84	2.97	2.62
WM-040	W	M	25.12	1.78	2.55	3.42	3.05
WM-041	W	M	24.97	2.19	1.75	2.98	2.14

Table A3. Arousal and valence ratings of the positive and negative images used in Experiments 5 and 6 (IAPS = International Affective Picture System; Lang et al., 2008).

Group	IAPS Number	Valence Rating	Arousal Rating	Valence Magnitude	IAPS Number	Valence Rating	Arousal Rating	Valence Magnitude
Positive			*High Arousal*				*Low Arousal*	
	1650	6.65	6.23	1.65	1410	7.00	4.17	2.00
	5621	7.57	6.99	2.57	1460	8.21	4.31	3.21
	5629	7.03	6.55	2.03	1500	7.24	4.12	2.24
	5950	5.99	6.79	0.99	1600	7.37	4.05	2.37
	7405	7.38	6.28	2.38	1661	6.14	4.05	1.14
	7650	6.62	6.15	1.62	1750	8.28	4.10	3.28
	8030	7.33	7.35	2.33	1850	6.15	4.06	1.15
	8034	7.06	6.30	2.06	1942	6.26	4.01	1.26
	8158	6.53	6.49	1.53	2170	7.55	4.08	2.55
	8163	7.14	6.53	2.14	2217	6.24	4.08	1.24
	8178	6.50	6.82	1.50	2222	7.11	4.08	2.11
	8179	6.48	6.99	1.48	2310	7.06	4.16	2.06
	8180	7.12	6.59	2.12	2339	6.72	4.16	1.72
	8185	7.57	7.27	2.57	2341	7.38	4.11	2.38
	8186	7.01	6.84	2.01	2342	6.20	4.06	1.20
	8190	8.10	6.28	3.10	2395	7.49	4.19	2.49
	8191	6.07	6.19	1.07	2521	5.78	4.10	0.78
	8200	7.54	6.35	2.54	4622	7.46	4.11	2.46
	8206	6.43	6.41	1.43	4700	6.91	4.05	1.91
	8341	6.25	6.40	1.25	5594	7.39	4.15	2.39
	8370	7.77	6.73	2.77	7284	6.21	4.06	1.21
	8400	7.09	6.61	2.09	7475	6.33	4.17	1.33
	8490	7.20	6.68	2.20	8205	6.62	4.17	1.62
	8492	7.21	7.31	2.21	8330	6.65	4.06	1.65
	8501	7.91	6.44	2.91	8497	7.26	4.19	2.26
Negative			*High Arousal*				*Low Arousal*	
	2730	2.45	6.80	2.55	2095	1.79	5.25	3.21
	2811	2.17	6.90	2.83	2205	1.95	4.53	3.05
	3010	1.71	7.16	3.29	2276	2.67	4.63	2.33
	3060	1.79	7.12	3.21	2301	2.78	4.57	2.22
	3150	2.26	6.55	2.74	2375	2.20	4.88	2.80
	3212	2.79	6.57	2.21	2455	2.96	4.46	2.04
	3213	2.96	6.82	2.04	2456	2.84	4.55	2.16
	3400	2.35	6.91	2.65	2750	2.56	4.31	2.44
	3500	2.21	6.99	2.79	2900	2.56	4.61	2.44
	6230	2.37	7.35	2.63	3300	2.74	4.55	2.26
	6231	2.49	6.82	2.51	3301	1.80	5.21	3.20
	6250	2.83	6.54	2.17	9000	2.55	4.06	2.45
	6260	2.44	6.93	2.56	9220	2.06	4.00	2.94
	6300	2.59	6.61	2.41	9265	2.60	4.34	2.40
	6313	1.98	6.94	3.02	9280	2.80	4.26	2.20
	6350	1.90	7.29	3.10	9290	2.88	4.40	2.12
	6510	2.46	6.96	2.54	9291	2.93	4.38	2.07

(*Continued*)

Table A3. Continued.

Negative		*High Arousal*				*Low Arousal*		
	6540	2.19	6.83	2.81	9330	2.89	4.35	2.11
	6550	2.73	7.09	2.27	9331	2.87	3.85	2.13
	8485	2.73	6.46	2.27	9342	2.85	4.49	2.15
	9163	2.10	6.53	2.90	9432	2.56	4.92	2.44
	9250	2.57	6.60	2.43	9435	2.27	5.00	2.73
	9600	2.48	6.46	2.52	9561	2.68	4.79	2.32
	9810	2.09	6.62	2.91	9830	2.54	4.86	2.46
	9908	2.34	6.63	2.66	9832	2.94	4.46	2.06

Appendix 2

ANOVA tables for Experiments 1–6.

Table A4. ANOVA results in Experiment 1.

Factor	df	MSE	F	*p*	η_p^2
	Role of Anticipation: RT				
Trial Type (TT)	**1, 47**	**736.12**	**9.06**	**.004**	**.162**
Previous Compatibility (PC)	**1, 47**	**597.03**	**11.64**	**.001**	**.198**
Current Compatibility (CC)	**1, 47**	**1183.91**	**51.60**	**< .001**	**.523**
TT×PC	1, 47	472.58	< 1	.694	.003
TT×CC	1, 47	323.51	<1	.630	.005
PC×CC	**1, 47**	**445.06**	**39.23**	**< .001**	**.455**
TT×PC×CC	1, 47	844.39	< 1	.963	< .001
	Role of Anticipation: PE				
TT	**1, 47**	**5.16**	**9.63**	**.003**	**.170**
PC	**1, 47**	**5.85**	**9.47**	**.003**	**.168**
CC	**1, 47**	**6.97**	**20.07**	**< .001**	**.299**
TT×PC	**1, 47**	**3.60**	**4.49**	**.039**	**.087**
TT×CC	1, 47	3.42	< 1	.757	.002
PC×CC	**1, 47**	**4.97**	**11.00**	**.002**	**.190**
TT×PC×CC	1, 47	3.06	< 1	.667	.004
	Role of Reaction: RT				
Previous Trial Type (PTT)	**2, 94**	**5374.08**	**25.25**	**< .001**	**.350**
PC	2, 94	1154.85	3.66	.062	.072
CC	**2, 94**	**1749.56**	**48.43**	**< .001**	**.508**
PTT×PC	2, 94	785.66	< 1	.645	.009
PTT×CC	2, 94	1060.75	< 1	.995	< .001
PC×CC	**2, 94**	**747.34**	**13.21**	**.001**	**.219**
PTT×PC×CC	2, 94	1391.21	< .1	.429	.018
	Role of Reaction: PE				
PTT	**2, 94**	**14.82**	**4.75**	**.011**	**.092**
PC	2, 94	8.21	< 1	.384	.016
CC	**2, 94**	**9.46**	**17.80**	**< .001**	**.275**
PTT×PC	2, 94	8.53	2.57	.082	.052
PTT×CC	2, 94	9.10	1.85	.162	.038
PC×CC	2, 94	10.10	2.10	.154	.043
PTT×PC×CC	2, 94	8.45	1.15	.320	.024

Note: Bold indicates a significant effect at alpha = .05.

Table A5. ANOVA results in Experiment 2.

Factor	df	MSE	F	*p*	η_p^2
	Role of Anticipation: RT				
Trial Type (TT)	**1, 47**	**642.39**	**20.76**	**< .001**	**.306**
Previous Compatibility (PC)	**1, 47**	**434.94**	**7.54**	**.009**	**.138**
Current Compatibility (CC)	**1, 47**	**642.64**	**63.94**	**< .001**	**.576**
TT×PC	1, 47	312.61	3.62	.063	.071
TT×CC	1, 47	364.13	1.02	.318	.021
PC×CC	**1, 47**	**612.23**	**8.88**	**.005**	**.159**
TT×PC×CC	1, 47	465.55	< 1	.848	.001

(*Continued*)

Table A5. Continued.

Factor	df	MSE	F	*p*	η_p^2
	Role of Anticipation: PE				
TT	**1, 47**	**9.55**	**5.29**	**.026**	**.101**
PC	1, 47	13.00	3.80	.057	.075
CC	**1, 47**	**11.70**	**10.56**	**.002**	**.184**
TT×PC	1, 47	4.60	< 1	.582	.007
TT×CC	1, 47	8.02	< 1	.543	.008
PC×CC	1, 47	12.35	2.04	.160	.042
TT×PC×CC	1, 47	5.66	< 1	.708	.003
	Role of Reaction: RT				
Previous Trial Type (PTT)	**2, 94**	**2602.97**	**28.49**	**< .001**	**.377**
PC	2, 94	1554.82	2.65	.111	.053
CC	**2, 94**	**1423.52**	**28.63**	**< .001**	**.379**
PTT×PC	2, 94	864.60	< 1	.694	.008
PTT×CC	2, 94	999.63	< 1	.525	.014
PC×CC	**2, 94**	**1043.67**	**7.41**	**.009**	**.136**
PTT×PC×CC	2, 94	807.26	< 1	.791	.005
	Role of Reaction: PE				
PTT	**2, 94**	**27.02**	**4.52**	**.013**	**.088**
PC	**2, 94**	**19.32**	**5.68**	**.021**	**.108**
CC	**2, 94**	**24.46**	**7.24**	**.010**	**.133**
PTT×PC	2, 94	16.18	< 1	.473	.016
PTT×CC	2, 94	12.84	< 1	.862	.003
PC×CC	2, 94	16.64	1.41	.241	.029
PTT×PC×CC	2, 94	16.60	1.15	.321	.024

Note: Bold indicates a significant effect at alpha = .05.

Table A6. ANOVA results in Experiment 3.

Factor	df	MSE	F	*p*	η_p^2
	Role of Anticipation: RT				
Group (G; between-subject)	**1, 46**	**89230.94**	**5.31**	**.026**	**.104**
Trial Type (TT)	**1, 46**	**1071.50**	**23.50**	**< .001**	**.338**
TT×G	1, 46	1071.50	< 1	.566	.007
Previous Compatibility (PC)	**1, 46**	**785.55**	**12.19**	**.001**	**.209**
PC×G	1, 46	785.55	< 1	.769	.002
Current Compatibility (CC)	**1, 46**	**931.53**	**34.65**	**< .001**	**.430**
CC×G	1, 46	931.53	< 1	.433	.013
TT×PC	1, 46	688.57	1.02	.316	.022
TT×PC×G	1, 46	688.57	1.41	.241	.030
TT×CC	**1, 46**	**720.70**	**5.77**	**.020**	**.111**
TT×CC×G	1, 46	720.70	< 1	.443	.013
PC×CC	**1, 46**	**361.76**	**31.21**	**< .001**	**.404**
PC×CC×G	1, 46	361.76	1.55	.219	.033
TT×PC×CC	1, 46	817.80	2.93	.094	.060
TT×PC×CC×G	1, 46	817.80	< 1	.860	<.001
	Role of Anticipation: PE				
G	1, 46	35.36	< 1	.449	.013
TT	1, 46	5.31	< 1	.370	.018
TT×G	1, 46	5.31	< 1	.829	.001
PC	1, 46	5.90	3.22	.079	.065
PC×G	1, 46	5.90	1.84	.182	.038
CC	**1, 46**	**7.37**	**14.69**	**< .001**	**.242**
CC×G	1, 46	7.37	3.75	.059	.075
TT×PC	1, 46	4.62	< 1	.371	.017
TT×PC×G	1, 46	4.62	< 1	.858	.001
TT×CC	1, 46	6.21	< 1	.679	.004
TT×CC×G	1, 46	6.21	< 1	.353	.019
PC×CC	1, 46	6.38	4.03	.051	.081
PC×CC×G	1, 46	6.38	< 1	.655	.004
TT×PC×CC	1, 46	8.22	< 1	.439	.013
TT×PC×CC×G	1, 46	8.22	< 1	.836	.001
	Role of Reaction: RT				
G	**1, 46**	**106174.44**	**5.20**	**.027**	**.102**

(*Continued*)

Table A6. Continued.

Factor	df	MSE	F	*p*	η_p^2
Previous Trial Type (PTT)	**1, 46**	**5708.14**	**66.22**	**< .001**	**.590**
PTT×G	1, 46	5708.14	< 1	.336	.020
PC	1, 46	856.41	1.17	.286	.025
PC×G	1, 46	856.41	1.68	.201	.035
CC	**1, 46**	**992.56**	**32.46**	**< .001**	**.414**
CC×G	1, 46	992.56	1.19	.281	.025
PTT×PC	1, 46	670.14	2.36	.131	.049
PTT×PC×G	1, 46	670.14	< 1	.953	< .001
PTT×CC	**1, 46**	**751.26**	**5.52**	**.023**	**.107**
PTT×CC×G	1, 46	751.26	< 1	.703	.003
PC×CC	**1, 46**	**694.41**	**13.23**	**< .001**	**.223**
PC×CC×G	1, 46	694.41	1.84	.181	.039
PTT×PC×CC	**1, 46**	**539.14**	**6.54**	**.014**	**.124**
PTT×PC×CC×G	1, 46	539.14	< 1	.464	.012
	Role of Reaction: PE				
G	1, 46	44.88	< 1	.663	.004
PTT	**1, 46**	**15.52**	**4.82**	**.033**	**.095**
PTT×G	1, 46	15.52	< 1	.780	.002
PC	**1, 46**	**6.78**	**8.42**	**.006**	**.155**
PC×G	1, 46	6.78	2.70	.107	.055
CC	**1, 46**	**9.83**	**5.84**	**.020**	**.113**
CC×G	1, 46	9.83	< 1	.339	.020
PTT×PC	1, 46	6.95	< 1	.635	.005
PTT×PC×G	1, 46	6.95	< 1	.821	.001
PTT×CC	1, 46	6.11	2.45	.124	.051
PTT×CC×G	1, 46	6.11	3.42	.071	.069
PC×CC	**1, 46**	**5.75**	**7.82**	**.008**	**.145**
PC×CC×G	1, 46	5.75	1.95	.169	.041
PTT×PC×CC	1, 46	6.47	2.32	.135	.048
PTT×PC×CC×G	1, 46	6.47	< 1	.529	.009

Note: Bold indicates a significant effect at alpha = .05.

Table A7. ANOVA results in Experiment 4.

Factor	df	MSE	F	*p*	η_p^2
	Role of Anticipation: RT				
Group (G, between-subject)	1, 46	99820.45	< 1	.757	.002
Trial Type (TT)	**1, 46**	**860.69**	**9.99**	**.003**	**.178**
TT×G	1, 46	860.69	< 1	.833	.001
Previous Compatibility (PC)	**1, 46**	**1213.05**	**14.01**	**.001**	**.233**
PC×G	1, 46	1213.05	< 1	.454	.012
Current Compatibility (CC)	**1, 46**	**941.67**	**61.63**	**< .001**	**.573**
CC×G	1, 46	941.67	< 1	.574	.007
TT×PC	1, 46	655.55	< 1	.821	.001
TT×PC×G	1, 46	655.55	3.70	.061	.074
TT×CC	1, 46	526.62	< 1	.765	.002
TT×CC×G	1, 46	526.62	< 1	.947	< .001
PC×CC	**1, 46**	**599.68**	**13.51**	**.001**	**.227**
PC×CC×G	1, 46	599.68	3.82	.057	.077
TT×PC×CC	1, 46	933.87	1.42	.240	.030
TT×PC×CC×G	1, 46	933.87	< 1	.717	.003
	Role of Anticipation: PE				
G	1, 46	60.64	< 1	.730	.003
TT	**1, 46**	**5.90**	**6.79**	**.012**	**.129**
TT×G	1, 46	5.90	< 1	.683	.004
PC	**1, 46**	**6.93**	**9.92**	**.003**	**.177**
PC×G	**1, 46**	**6.93**	**4.79**	**.034**	**.094**
CC	**1, 46**	**10.35**	**13.77**	**.001**	**.230**
CC×G	1, 46	10.35	2.84	.099	.058
TT×PC	1, 46	11.39	1.37	.248	.029
TT×PC×G	1, 46	11.39	< 1	.437	.013
TT×CC	1, 46	7.72	1.13	.294	.024
TT×CC×G	1, 46	7.72	1.14	.290	.024

(*Continued*)

Table A7. Continued.

Factor	df	MSE	F	*p*	η_p^2
PC×CC	**1, 46**	**7.45**	**7.32**	**.010**	**.137**
PC×CC×G	1, 46	7.45	< 1	.362	.018
TT×PC×CC	1, 46	12.20	< 1	.860	.001
TT×PC×CC×G	1, 46	12.20	< 1	.440	.013
	Role of Reaction: RT				
G	1, 46	95314.10	< 1	.934	< .001
Previous Trial Type (PTT)	**1, 46**	**3696.62**	**29.89**	**< .001**	**.394**
PTT×G	1, 46	3696.62	1.20	.281	.025
PC	1, 46	1454.86	3.08	.087	.062
PC×G	1, 46	1454.86	1.65	.209	.034
CC	**1, 46**	**972.33**	**83.54**	**< .001**	**.645**
CC×G	1, 46	972.33	< 1	.924	< .001
PTT×PC	1, 46	1167.10	2.83	.097	.059
PTT×PC×G	1, 46	1167.10	< 1	.435	.013
PTT×CC	1, 46	823.23	1.70	.204	.035
PTT×CC×G	1, 46	823.23	< 1	.457	.012
PC×CC	**1, 46**	**789.97**	**10.65**	**.002**	**.189**
PC×CC×G	1, 46	789.97	< 1	.703	.003
PTT×PC×CC	1, 46	412.48	2.92	.097	.059
PTT×PC×CC×G	1, 46	412.48	1.58	.209	.034
	Role of Reaction: PE				
G	1, 46	77.49	< 1	.949	< .001
PTT	**1, 46**	**16.92**	**11.96**	**.001**	**.206**
PTT×G	1, 46	16.92	< 1	.782	.002
PC	**1, 46**	**9.38**	**8.72**	**.005**	**.159**
PC×G	1, 46	9.38	< 1	.348	.019
CC	**1, 46**	**11.26**	**10.69**	**.002**	**.189**
CC×G	1, 46	11.26	2.36	.132	.049
PTT×PC	1, 46	7.65	1.34	.253	.028
PTT×PC×G	1, 46	7.65	< 1	.939	< .001
PTT×CC	1, 46	9.11	1.68	.201	.035
PTT×CC×G	1, 46	9.11	< 1	.375	.017
PC×CC	1, 46	7.13	< 1	.432	.013
PC×CC×G	1, 46	7.13	< 1	.512	.009
PTT×PC×CC	**1, 46**	**10.43**	**7.58**	**.008**	**.142**
PTT×PC×CC×G	1, 46	10.43	< 1	.543	.008

Note: Bold indicates a significant effect at alpha = .05.

Table A8. ANOVA results in Experiment 5.

Factor	df	MSE	F	*p*	η_p^2
	Role of Anticipation: RT				
Group (G; between-subject)	1, 46	50034.71	2.48	.122	.051
Trial Type (TT)	1, 46	747.89	3.94	.053	.079
TT×G	1, 46	747.89	1.39	.245	.029
Previous Compatibility (PC)	**1, 46**	**574.94**	**27.15**	**< .001**	**.371**
PC×G	**1, 46**	**574.94**	**4.30**	**.044**	**.085**
Current Compatibility (CC)	**1, 46**	**622.06**	**38.33**	**< .001**	**.455**
CC×G	1, 46	622.06	< 1	.898	< .001
TT×PC	1, 46	903.35	1.17	.285	.025
TT×PC×G	1, 46	903.35	< 1	.608	.006
TT×CC	1, 46	1008.02	2.13	.152	.044
TT×CC×G	1, 46	1008.02	< 1	.482	.001
PC×CC	**1, 46**	**683.05**	**15.75**	**< .001**	**.255**
PC×CC×G	1, 46	683.05	< 1	.893	< .001
TT×PC×CC	1, 46	366.96	< 1	.885	< .001
TT×PC×CC×G	1, 46	366.96	< 1	.589	.006
	Role of Anticipation: PE				
G	1, 46	49.69	< 1	.989	< .001
TT	**1, 46**	**9.16**	**12.00**	**.001**	**.207**
TT×G	1, 46	9.16	< 1	.344	.019
PC	**1, 46**	**7.93**	**6.58**	**.014**	**.125**
PC×G	1, 46	7.93	< 1	.426	.014

(*Continued*)

Table A8. Continued.

Factor	df	MSE	F	*p*	η_p^2
CC	1, 46	6.65	2.36	.132	.049
CC×G	1, 46	6.65	< 1	.981	< .001
TT×PC	1, 46	6.67	< 1	.417	.014
TT×PC×G	1, 46	6.67	< 1	.512	.009
TT×CC	1, 46	5.29	< 1	.811	.001
TT×CC×G	1, 46	5.29	< 1	.411	.015
PC×CC	**1, 46**	**10.67**	**6.09**	**.017**	**.117**
PC×CC×G	1, 46	10.67	< 1	.607	.006
TT×PC×CC	**1, 46**	**6.06**	**4.17**	**.047**	**.083**
TT×PC×CC×G	1, 46	6.06	< 1	.989	< .001
	Role of Reaction: RT				
G	1, 46	93846.08	< 1	.775	.002
Previous Trial Type (PTT)	**1, 46**	**4032.05**	**26.85**	**< .001**	**.369**
PTT×G	**1, 46**	**4032.05**	**9.15**	**< .001**	**.166**
PC	1, 46	1124.12	3.42	.071	.069
PC×G	1, 46	1124.12	< 1	.588	.006
CC	**1, 46**	**935.00**	**48.24**	**< .001**	**.512**
CC×G	1, 46	935.00	< 1	.779	.002
PTT×PC	**1, 46**	**1217.74**	**3.70**	**.028**	**.075**
PTT×PC×G	**1, 46**	**1217.74**	**5.12**	**.008**	**.100**
PTT×CC	1, 46	1609.01	1.32	.271	.028
PTT×CC×G	1, 46	1609.01	< 1	.777	.005
PC×CC	**1, 46**	**1770.53**	**8.76**	**.005**	**.160**
PC×CC×G	1, 46	1770.53	< 1	.969	< .001
PTT×PC×CC	1, 46	1338.90	< 1	.971	.001
PTT×PC×CC×G	1, 46	1339.90	< 1	.644	.010
	Role of Reaction: PE				
G	1, 46	199.14	< 1	.738	.002
PTT	**1, 46**	**30.09**	**17.53**	**< .001**	**.276**
PTT×G	1, 46	30.09	< 1	.524	.014
PC	1, 46	17.99	1.92	.173	.040
PC×G	1, 46	17.99	< 1	.571	.007
CC	**1, 46**	**28.90**	**4.09**	**.049**	**.082**
CC×G	1, 46	28.90	< 1	.529	.009
PTT×PC	**1, 46**	**13.76**	**4.47**	**.014**	**.089**
PTT×PC×G	1, 46	13.76	< 1	.436	.018
PTT×CC	1, 46	20.73	1.40	.252	.030
PTT×CC×G	1, 46	20.73	< 1	.749	.006
PC×CC	1, 46	20.91	< 1	.392	.016
PC×CC×G	1, 46	20.91	< 1	.846	.001
PTT×PC×CC	**1, 46**	**21.18**	**3.75**	**.027**	**.075**
PTT×PC×CC×G	1, 46	21.18	< 1	.807	.005

Note: Bold indicates a significant effect at alpha = .05.

Table A9. ANOVA results in Experiment 6.

Factor	df	MSE	*F*	*p*	η_p^2
	Role of Anticipation: RT				
Group (G; between-subject)	1, 46	62893.27	< 1	.512	.009
Trial Type (TT)	**1, 46**	**593.08**	**8.88**	**.005**	**.162**
TT×G	1, 46	593.08	2.03	.161	.042
Previous Compatibility (PC)	**1, 46**	**827.37**	**8.27**	**.006**	**.152**
PC×G	1, 46	827.37	< 1	.734	.003
Current Compatibility (CC)	**1, 46**	**568.30**	**68.83**	**< .001**	**.599**
CC×G	1, 46	568.30	< 1	.531	.009
TT×PC	1, 46	311.95	< 1	.520	.009
TT×PC×G	1, 46	311.95	< 1	.597	.006
TT×CC	1, 46	430.84	1.33	.254	.028
TT×CC×G	1, 46	430.84	2.22	.143	.046
PC×CC	1, 46	560.58	3.89	.055	.078
PC×CC×G	1, 46	560.58	< 1	.528	.009
TT×PC×CC	1, 46	437.20	1.66	.205	.035
TT×PC×CC×G	1, 46	437.20	< 1	.673	.004

(*Continued*)

Table A9. Continued.

Factor	df	MSE	*F*	*p*	η_p^2
	Role of Anticipation: PE				
G	1, 46	104.74	< 1	.646	.005
TT	1, 46	14.88	2.74	.104	.056
TT×G	1, 46	14.88	< 1	.574	.007
PC	1, 46	8.63	2.24	.142	.046
PC×G	1, 46	8.63	< 1	.569	.007
CC	**1, 46**	**13.25**	**9.31**	**.004**	**.168**
CC×G	1, 46	13.25	< 1	.339	.020
TT×PC	1, 46	8.45	1.87	.178	.039
TT×PC×G	1, 46	8.45	< 1	.595	.006
TT×CC	1, 46	14.91	< 1	.527	.009
TT×CC×G	1, 46	14.91	< 1	.931	< .001
PC×CC	**1, 46**	**9.58**	**10.55**	**.002**	**.187**
PC×CC×G	1, 46	9.58	< 1	.863	.001
TT×PC×CC	1, 46	9.79	< 1	.727	.003
TT×PC×CC×G	1, 46	9.79	< 1	.336	.020
	Role of Reaction: RT				
G	1, 46	98695.79	< 1	.606	.006
Previous Trial Type (PTT)	2, 92	1329.03	1.17	.314	.025
PTT×G	2, 92	1329.03	3.04	.053	.062
PC	**2, 92**	**716.06**	**15.52**	**< .001**	**.252**
PC×G	2, 92	716.06	< 1	.378	.017
CC	**2, 92**	**1102.60**	**54.95**	**< .001**	**.500**
CC×G	2, 92	1102.60	< 1	.550	.008
PTT×PC	2, 92	798.83	< 1	.899	.002
PTT×PC×G	2, 92	798.83	< 1	.905	.002
PTT×CC	2, 92	992.60	1.55	.217	.033
PTT×CC×G	2, 92	992.60	2.37	.099	.049
PC×CC	2, 92	1192.67	3.04	.088	.062
PC×CC×G	2, 92	1192.67	2.27	.139	.047
PTT×PC×CC	2, 92	878.45	< 1	.632	.010
PTT×PC×CC×G	2, 92	878.45	< 1	.559	.013
	Role of Reaction: PE				
G	1, 46	233.37	< 1	.590	.006
PTT	**2, 92**	**28.09**	**3.68**	**.029**	**.074**
PTT×G	2, 92	28.09	1.04	.357	.022
PC	2, 92	19.70	< 1	.369	.018
PC×G	2, 92	19.70	< 1	.870	.001
CC	**2, 92**	**13.26**	**26.05**	**< .001**	**.362**
CC×G	2, 92	13.26	< 1	.494	.010
PTT×PC	2, 92	18.57	< 1	.485	.016
PTT×PC×G	2, 92	18.57	< 1	.604	.011
PTT×CC	2, 92	16.45	1.96	.146	.041
PTT×CC×G	2, 92	16.45	< 1	.478	.016
PC×CC	**2, 92**	**23.88**	**8.95**	**.004**	**.163**
PC×CC×G	2, 92	23.88	< 1	.951	< .001
PTT×PC×CC	2, 92	14.43	< 1	.395	.020
PTT×PC×CC×G	2, 92	14.43	< 1	.851	.004

Note: Bold indicates a significant effect at alpha = .05.

Appendix 3

Bayesian ANOVA results in Experiments 1–6

In addition to the classic ANOVAs reported in the main texts above, RT and PE were also submitted to Bayesian ANOVAs with the same structures as above by using JASP (Ver. 0.18.3.0; https://jasp-stats.org/). In the analysis, we first determined the best fitting model and then examined Bayes factor (BF) for the best fitting model compared against all possible models (i.e. BF_{01} where the best fitting model serves as the null model). According to Lee and Wagenmakers's (2013) criteria,[3] $BF_{01} > 10$ provides strong evidence supporting the null model (the best fitting model), so one can consider that the data provide less than strong evidence supporting the best fitting model if $BF_{01} < 10$. In this case, the alternative model could be considered to be a viable model to explain the data as well. If $BF_{01} > 10$, the data provide strong evidence against the alternative model in favor of the best fitting model. Because the Bayesian ANOVA tables are large (and most details are irrelevant), we only summarise the outcomes below and do not report

them. Those who are interested in evaluating the outcomes of the Bayesian analysis are advised to retrieve the JASP files containing the analysis results from our OSF page (https://osf.io/y54pu/).

Experiment 1

The Role of Anticipation

For RT, the best model was that including all main effects of Trial Type, Previous Compatibility, and Current Compatibility, as well as the interaction between Previous Compatibility and Current Compatibility. Two models yielded BF_{01} smaller than 10 as compared against this best fitting model, which included either the interaction between Trial Type and Compatibility ($BF_{01} = 5.96$) or the interaction between Trial Type and Previous Compatibility ($BF_{01} = 6.46$). No model involving the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility, produced $BF_{01} < 10$, indicating that the sequential modulation did not depend on the anticipation of an incoming emotional stimulus.

For PE, the best model included the main effects of all three factors and the interaction between Previous Compatibility and Current Compatibility. Three models yielded BF_{01} smaller than 10 against the best model, which included either the interaction between Trial Type and Previous Compatibility, the interaction between Trial Type and Current Compatibility, or both of these interactions. No models including the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility, yielded $BF_{01} < 10$.

The Role of Reaction

For RT, the best model included the main effects of Trial Type and Current Compatibility. Two models that yielded $BF_{01} < 10$ involved the main effect of Previous Compatibility and the interaction between Previous Compatibility and Current Compatibility or the main effect of Previous Compatibility, in addition to those terms in the best model. Again, none of the models involving the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility, produced $BF_{01} < 10$.

For PE, the best model was also that including the main effects of Trail Type and of Current Compatibility. Two models that yielded $BF_{01} < 10$ against the best model involved the interaction between Trial Type and Current Compatibility or the main effect of Previous Compatibility, in addition to those terms in the best model. Again, no models that involved the three way interaction among Trial Type, Previous Compatibility, and Current Compatibility, yield BF_{01} smaller than 10.

Experiment 2

The Role of Anticipation

For RT, the best model included the main effects of Trial Type, Previous Compatibility, and Current Compatibility, as well as the interaction between Previous and Current Compatibility. There were three models that produced $BF_{01} < 10$, which included either the interaction between Trial Type and Previous Compatibility, that between Trial Type and Current Compatibility, or both. No model involving the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility produced $BF_{01} < 10$.

For PE, there were two best models; one that included the main effects of Trial Type and of Current Compatibility, and the other that included the main effects of all three factors. There were 10 additional models that produced $BF_{01} < 10$, but none of the models included the 3-way interaction among all three factors.

The Role of Reaction

For RT, the best model include the main effects of all three factors and the interaction between Previous and Current Compatibility. None of the models involving the 3-way interaction among all three factors produced $BF_{01} < 10$.

For PE, the best model included the main effects of all three factors and none of the interactions. Ten models produced $BF_{01} < 10$, but no model involving the interaction among all three factors produced $BF_{01} < 10$.

Experiment 3

The Role of Anticipation

For RT, the best model was the one that included the main effects of all four factors and the interaction between Previous and Current Compatibility, as well as the interactions of Trial Type with Group, Previous Compatibility, and Current Compatibility, and the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility. There were four additional models that produced $BF_{01} < 10$, one of which also included the three way interaction among Trial Type, Previous Compatibility, and Current Compatibility. Thus, the sequential modulation of the flanker effect was reliably smaller when an emotional trial was cued than when it was not. Interestingly, however, none of the models involving an interactions of Group with Previous or Current Compatibility produced $BF_{01} < 10$, indicating that there was a reduction in the sequential modulation of the flanker effect when an emotional trial was cued, but the valence did not matter.

For PE, the best model only included the main effect of Current Compatibility. There were nine models that produced $BF_{01} < 10$, but none of them involved a 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility, or a 4-way interaction among Trial Type, Previous Compatibility, Current Compatibility, and Group.

The Role of Reaction

For RT, 18 models produced $BF_{01} < 10$. Among the top 10 models, eight models included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility, while none of them included a 4-way interaction among these three factors and Group. The results indicate that the sequential modulation of the flanker effect depended on valence-laden stimuli on the preceding trial, but it did not depend on whether the valence was positive or negative.

For PE, there were also 18 models that produced $BF_{01} < 10$, but none of the top 10 models included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility, providing little evidence that the sequential modulation of the flanker effect depended on the preceding valence-laden stimuli.

Experiment 4

The Role of Anticipation

For RT, the best model was that involving the main effects of the three factors and the interaction between Previous and Current Compatibility. Three additional models produced $BF_{01} < 10$, but none of them included the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility.

For PE, there were 24 models that produced $BF_{01} < 10$, but none of them included the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility either. These results provided evidence against the hypothesis that the sequential modulation depended on anticipating valence-laden stimuli.

The Role of Reaction

For RT, although the classic ANOVA on RT reported in the main text showed little indication that the sequential modulation depended on Previous Trial Type, the Bayesian ANOVA did showed that the best model included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility. The two additional models that also produced $BF_{01} < 10$ did not include the 3-way interaction. The sequential modulation of the flanker effect was larger after non-emotional trials (26 ms) than after emotional trials (11 ms).

For PE, the best model included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility.

Experiment 5

The Role of Anticipation

For RT, the best model included the main effects of all four factors, and the interactions between Group and Previous Compatibility, between Group and Current Compatibility, and between Previous Compatibility and Current Compatibility, as well as the 3-way interaction among Group, Previous Compatibility, and Current Compatibility. The second best model produced $BF_{01} < 10$, indicating that the sequential modulation of the flanker effect depended on the participant group. Nevertheless, the difference in the sequential modulation between the two groups was rather small; the sequential modulation was 22 ms for the positive group and 20 ms for the negative group.

For PE, there were 13 models that produced $BF_{01} < 10$. The best model included the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility, although none of other models but one included this interaction. The sequential modulation of the flanker effect was smaller for non-emotional trials ($M = .62\%$) than for emotional trials ($M = 2.67\%$).

The Role of Reaction

For RT, the best model included the main effects of all four factors, the interaction between Previous and Current Compatibility, between Group and Previous Trial Type, and between Group and Current Compatibility. Three other models produced $BF_{01} < 10$, but none of them included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility.

For PE, nine models produced $BF_{01} < 10$. Unlike the ANOVA above, none of the models included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility. Hence, the Bayesian ANOVAs did not support the hypothesis that the sequential modulation depended on reacting to emotional stimuli.

Experiment 6

The Role of Anticipation

For RT, the best model included the main effects of the four factors and the interaction between Trial Type and Current Compatibility, but not the interaction between Previous and Current Compatibility, although three of the eight other models that produced $BF_{01} < 10$ still included the interaction between Previous and Current Compatibility.

For PE, the best model only included the main effects of Previous Compatibility and of Current Compatibility, and their interaction. Five additional models produce $BF_{01} < 10$, but none of them included the 3-way interaction among Trial Type, Previous Compatibility, and Current Compatibility. There were no evidence that the sequential modulation depended on anticipating emotional stimuli.

The Role of Reaction

For RT, the best model only included the main effects of Previous Compatibility and Current Compatibility, but the close second best included the interaction between these factors as well ($BF_{01} = 1.522$). Another model also produced $BF_{01} < 10$, which included the main effects of Previous Trial Type, of Previous Compatibility, and of Current Compatibility. There was no indication that the sequential modulation depended on previous trial type or group.

For PE, the best model included the main effects of Previous Trial Type, of Previous Compatibility, and of Current Compatibility, and the interaction between Previous and Current Compatibility. Seven additional models produced $BF_{01} < 10$, but none of them included the 3-way interaction among Previous Trial Type, Previous Compatibility, and Current Compatibility. Hence, there was little evidence that reacting to emotional stimuli influenced the sequential modulation of the flanker effect.