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Cognitive control under high threat: the effect of shock on the congruency sequence effect

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Abstract

The congruency sequence effect (CSE) refers to the reduced distractor interference following conflict trials compared to following non-conflict trials. According to the affective account, the enhancement of cognitive control necessary to resolve the negative affect caused by conflict drives the CSE. Research supporting this view has shown that the induction of negative affect leads to increases in the CSE. In contrast, the dual competition model predicts that the processing of task-irrelevant high-threatening stimuli consumes the resources required for cognitive control, reducing the CSE. To test the impact of threat on the CSE, the present study examined the modulation of the CSE in the threatening context induced by electric shocks. Participants were to perform two Simon tasks or two flanker-compatibility tasks both under threat of shock and without such threat. Consistent with the dual competition model, the CSE obtained in the safe context disappeared under the threat of shock, regardless of whether participants performed stimulus-based conflict tasks or response-based conflict tasks. This paper discusses the implications of this finding in relation to the CSE's driving motivation, aiming to reconcile these discrepant results with previous findings supporting the affective account.

Keywords Negative affect · Cognitive control · Electric shock · Congruency sequence effect

Cognitive control impacts every aspect of life, from low-level attention (Posner and Snyder 1975) to personality (Sadeh and Verona 2008). Researchers have extensively examined the impacts of emotion on cognitive control and vice versa (Birk et al. 2018; Ochsner and Gross 2005; Zinchenko et al. 2015). For instance, research has suggested that negative emotion is an integral part of cognitive control processes (Inzlicht et al. 2015). Specifically, studies have found that conflict has negative connotations and people exercise cognitive control to resolve negative emotion (Botvinick 2007; van Steenbergen 2015). One phenomenon researchers have identified as reflecting negative emotion-driven cognitive control processes is the congruency sequence effect.

The congruency effect (CE) refers to slower responses and/or higher error rates on conflict trials (i.e., incongruent trials) than non-conflict trials (i.e., congruent trials). Traditionally, the CE has been used to assess the extent to which task-irrelevant distractors are processed. Researchers have found that the CE is further modulated by previous trial congruency—reduced CE following incongruent trials compared to following congruent trials—which is a phenomenon called the congruency sequence effect (CSE; Gratton et al. 1992). According to the conflict monitoring theory, the CSE occurs when conflict is detected by a conflict monitoring system which is assumed to be located in the anterior cingulate cortex (ACC), and enhances cognitive control to reduce conflict on the subsequent trial (Botvinick et al. 2001). Neuroscientific and behavioral evidence indicates that the occurrence of conflict triggers heightened activation of the ACC (Kerns et al. 2004), which further sends signals to higher regions that enhance the processing of task-relevant information (Egner and Hirsch 2005; Notebaert and Verguts 2008) or suppress the processing of task-irrelevant information (Stürmer et al. 2002; Kim et al. 2015).

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Affective account on the CSE

Botvinick (2007) suggested that conflict might be registered as a cost or aversive signal inducing negative affect given the ACC's involvement in both conflict detection and the evaluation of negative outcomes. Reinforcing the notion, subsequent studies showed that incongruent stimuli prime negative affect (Dreisbach and Fischer 2012; Fritz and Dreisbach 2013) and trigger an avoidance strategy (Dignath and Eder 2015; Dignath et al. 2015). Furthermore, it has been suggested that the CSE is engendered by the aversive signal of conflict to reduce negative affect in subsequent trials (Dreisbach and Fischer 2015). In support, the CSE has been found to be modulated by affective manipulation. For instance, van Steenbergen et al. (2010) and Schuch and Koch (2015) demonstrated that negative moods enhanced the CSE compared to positive mood, which the authors interpreted that conflict becomes more salient in negative mood. Also, van Steenbergen et al. (2009, 2012) found that random reward cues eliminated the CSE, which they interpreted that positive stimuli canceled out the aversive quality of conflict, triggering the sequential modulation of the CE. Additionally, an electrophysiological index associated with the activity of the ACC showed more sustained effects following conflict than following non-conflict in loss conditions but not in reward conditions, indicating more engagement of the ACC following the loss. As for the underlying mechanism, Kanske and Kotz (2010) showed that the ventral part of the ACC integrates information from the amygdala and the dorsal part of ACC and enhances conflict resolution in emotional contexts.

Researchers have suggested that while incongruent stimuli may have negative connotations, subsequent conflict resolution could be a positive and rewarding experience (Botvinick and Braver 2015; Braem et al. 2012; van Steenbergen et al. 2015). Furthermore, the motivation to pursue such intrinsic reward experience by increasing cognitive control might be a critical factor driving conflict resolution. In support, Braem et al. (2012) found enhanced CSE preceded by reward cues when rewards were contingent on participants' performance which is in direct contrast with the results of van Steenbergen et al.'s (2009, 2012) experiments, in which reward delivery was not contingent on participants' performance. Such contrasting results demonstrate that not only affect but also motivation may determine whether cognitive adjustment driven by conflict takes place or not.

Dual competition model

In contrast to the affective account of the CSE, the dual competition model predicts that emotion will have an adverse effect on cognitive control (Pessoa 2009). It posits that affective stimuli compete for attention at both the perceptual stage and the executive stage, which includes the processing of conflict resolution, and that emotional and motivational value further modulate their impact. The model specifically suggests that the processing of task-irrelevant emotional stimuli can divert the attentional resources required for cognitive control because emotional stimuli are prioritized in cognitive processing. In particular, the level of threat imposed by task-irrelevant stimuli plays a critical role in determining how emotion interferes with task performance. If the level of threat of emotional stimuli is low, the processing will be prioritized but in a moderate way. On the other hand, high threat emotional stimuli require extensive resource mobilization and dramatically interfere with task performance. In Padmala et al. (2011) experiment, in which emotional pictures were presented in between task stimuli, the researchers obtained the CSE following the presentation of neutral images but not following the presentation of negative images. They suggested they found no CSE after presenting the negative pictures because the processing of negative emotions consumed the resources required for conflict resolution.

Reconciling the two accounts

One possible explanation for the discrepanciess between studies that observed the effect of mood manipulation, on the one hand, Schuch and Koch's (2015) and van Steenbergen et al.'s (2010) experimental findings and, on the other, those of Padmala et al. (2011), is that the levels of threat imposed by the task-irrelevant emotional stimuli differed. Specifically, both Schuch and Koch's and van Steenbergen et al.'s experiments achieved mood manipulation by having participants imagine and write about a particular mood and listen to classical music, whereas Padmala et al.'s experiment used highly disturbing negative pictures. Another potential factor that led to divergent effects of emotion on the CSE is related to motivation. Although not as explicit as reward, emotional context may mediate motivation for performance. For instance, the classical learned helplessness experiments (Maier and Seligman 1976) demonstrate that when exposed to inescapable shocks, a subject was immobilized even when the escape was possible because previous experience of non-contingency between response and outcomes undermined the motivation to act. Similarly, the occurrence of highly disturbing emotional stimuli irrelevant to task performance may decrease motivation for conflict adjustment because enhancing conflict resolution does not resolve negative emotion.

CSE by conflict type

Additionally, despite many literatures elaborating on different mechanisms of the CSE by conflict type (Egner 2008; Egner and Hirsch 2005; Lee and Cho 2013; Stürmer et al. 2002; Verbruggen et al. 2006), whether the modulation of the CSE by affective information would differ based on conflict type remain scarce. Specifically, researchers have divided conflict types into two categories: stimulus-based conflicts, which take place between stimulus dimensions; and response-based conflicts, which arise only between responses activated by task-relevant and task-irrelevant features (Kornblum et al. 1990). For instance, in the flanker-compatibility task (Eriksen and Eriksen 1974), conflict arises when the feature of the central target to which participants must respond differs from the features of the distracting flankers. In the Simon task (Simon 1990), participants must respond to a non-spatial feature of the target presented to the left or right side of the display with a left or right keypress response. Conflict takes place between the response activated by the task-relevant feature and the response activated by the location of the target. Previous studies have suggested that the effect of emotion on the CSE might be task-specific (Dignath et al. 2017; Stürmer et al. 2011), but these studies were limited because they did not directly compare the modulations of the CSE by conflict type in one experimental setting.

Present study

The main purpose of the present study was to investigate the impact of task-irrelevant emotion with a relatively high level of threat on the CSE. Participants performed conflict tasks in a threatening context, in which electric shocks could be administered independent of task performance, and in a safe context without such threat. Participants were told that the electric shock would be randomly administered once within the block followed by the cue. The hypothesis was made that the high-threatening and task-irrelevant electric shock would interfere with conflict adjustment. The level of arousal induced by the electric shock was assessed by skin conductance level. Additionally, the flanker-compatibility and Simon tasks were used to determine whether the impact of the threat of shock generalized to different conflict type.

In order to avoid bottom-up repetition priming on the CSE, an alternate-task paradigm was used (Kim and Cho 2014). When a task involves a small number of stimulus and response, the stimulus and response features may repeat over consecutive trials. Hommel et al. (2004) suggested that stimulus and response features in a trial become temporarily bound into an episodic event file. When stimulus and response features completely repeat, the performance on current trial may be facilitated. When they do not repeat, there is no interference by the previous episode. On the other hand, when the feature partially repeats, the previous trial episode may interfere with the current trial episode, leading to a slow response. Hommel et al. suggested that feature integration is completely confounded with sequential modulation by conflict adjustment. Therefore, without controlling the repetition, the bottom-up confounds may persist under emotion manipulation, meaning the impact of emotion on conflict adjustment may not manifest (Dignath et al. 2017). In the present study, by alternating two tasks consisting of different stimulus and response features, the repetition of features over consecutive trials was avoided.

Lastly, individual differences may mediate the impact of induced emotion on cognitive control, since individual levels of emotional reactivity, regulation, and cognitive control vary (Gray 2001). In particular, previous studies have indicated that individuals with high trait anxiety levels demonstrate heightened emotional reactivity (Mennin et al. 2007) and low levels of cognitive control (Eysenck et al. 2007). Moreover, research has shown that, due to its unpredictable nature, the threat of electric shock unrelated to task performance induces anxiety in experimental settings (Robinson et al. 2013). In this regard, it was hypothesized that individuals with varying anxiety levels would respond to the threatening context differently, mediating the effect of context on task performance.

Methods

Participants

A total of 96 undergraduate students (50 females, mean age = 22.7) at Korea University who had no histories of psychological disorders and were not taking medication voluntarily participated in this study in exchange for KRW 8000 (around 7.5 USD). In the study, 48 participants were assigned to perform the flanker-compatibility task (26 females, mean age = 23.2), and the other 48 participants were required to perform the Simon task (24 females, mean age = 22.1). To assess proper sample sizes, a priori power analysis using G*Power 3.1 software (Faul et al. 2007) was performed. The effect sizes were derived from previous studies that observed the effect of negative emotion on the sequential modulation of the CE (Padmala et al. 2011) and the effect of motivation on the contextual modulation of the CE (Soutschek et al. 2014, Experiment 2) which ranged

Table 1 Demographic information of participants

	N	%
Female	50	52
Right-handed	94	98
	M	*SD*
Age (years)	22.7	2.27
Spielberger state anxiety	37.08	7.9
Spielberger trait anxiety	42.76	7.44

M mean, *SD* standard deviation

from .1 to .375 based on reported η_p^2. Then, power analyses for repeated measures analysis of variance (ANOVA) with the power of 0.95 and an alpha level of 0.05 revealed that the appropriate sample size should be between 14 to 56. All participants had normal or corrected-to-normal visual acuity and color vision. Two participants were left-handed. Table 1 presents the demographic information of the participants. The study was approved by the Korea University Institutional Review Board (KU-IRB-16-177-A-1).

Personality questionnaires

Prior to the experiment, participants completed Korean translated versions of the State-Trait-Anxiety-Inventory (STAI; Spielberger et al. 1983), which was used to assess participants' anxiety levels.

Stimuli and Behavioral Paradigm

Stimuli were controlled using Psychtoolbox 3 implemented in MATLAB 2008b. Each trial consisted of a fixation display and a target display. In the fixation display, a white cross (0.6° × 0.6°) was presented at the center of the screen as a fixation point. In the flanker-compatibility task, the target display contained a target circle (1.07° in a diameter) and two flanker circles (1.07° in a diameter). Flankers were presented horizontally on even trials and vertically on odd trials. For both the horizontal and vertical presentations, the flanker circles were presented 1.91° apart from the target. Trial congruency was determined based on the match or mismatch between the target and distractor colors. In the Simon task, the target display contained a target square (1.07° × 1.07°) presented 2.98° to the left or right side of the fixation point. Trial congruency was determined based on the match or mismatch between the location of the target and its required response side. In both tasks, participants were asked to respond to the color of the target. Red (R = 255, G = 0, B = 0) and yellow (R = 255, G = 255, B = 0) were used as stimulus colors on the even trials, and green (R = 0, G = 255, B = 0) and blue (R = 0, G = 0, B = 255) were used on the odd trials. All stimuli were displayed on a gray background on a 21.5 inch LCD monitor (LG Flatron with W2261-PF, Seoul, Korea) with a screen resolution of 1280 × 768 pixels and viewed at a distance of around 60 cm. Responses were made using four fingers to press four keys on a standard computer keyboard. Participants were asked to press the "f" key with their left index finger for the red target, the "j" key with their right index finger for the yellow target, the "d" key with their left middle finger for the green target, and the "k" key with their right middle finger for the blue target. Red and yellow stimuli were presented as the target and/or distractor on even trials, and green and blue stimuli were presented as the target and/or distractor on odd trials. Thus, two different stimulus and response sets were alternated to avoid the repetition of stimuli and responses on consecutive trials (Kim and Cho 2014) and thereby minimize the feature integration effect (Hommel et al. 2004).

Electric shock

To induce anxiety, a moderate intensity electric shock was administered for 500 ms to the left ring and little fingers using electric stimulators (Coulbourn Instruments, Whitehall, PA, USA). Electric stimulators were attached prior to the main experiment following practice trials. Participants were asked to adjust the intensity of the shock to "highly unpleasant but not painful."

SC data

Throughout the experiment, SC data were collected using a PowerLab 4/30 amplifier with a ML116 GSR Amp (ADInstruments, Sydney, Australia) through electrodes (MLT116F) attached to the right ring and little fingers at a sampling rate of 200 Hz.

Task procedure

Except for the target display, the procedures for the flanker-compatibility task and the Simon task were the same. Each experiment included 24 blocks (12 blocks each for the safe and threatening contexts) preceded by a 30-trial practice block. After every four blocks, participants received a 1-min break. Participants underwent two consecutive safe blocks and two consecutive threatening blocks alternatively. A white square (2.09° × 2.09°) and a diamond (2.09° × 2.09°) were used as cues for the safe and threatening contexts, counterbalanced across participants, to indicate the block type at the beginning of the blocks. A cue was presented at the beginning of each block for 1500 ms. Participants were told that they that had a 66% chance of receiving electric

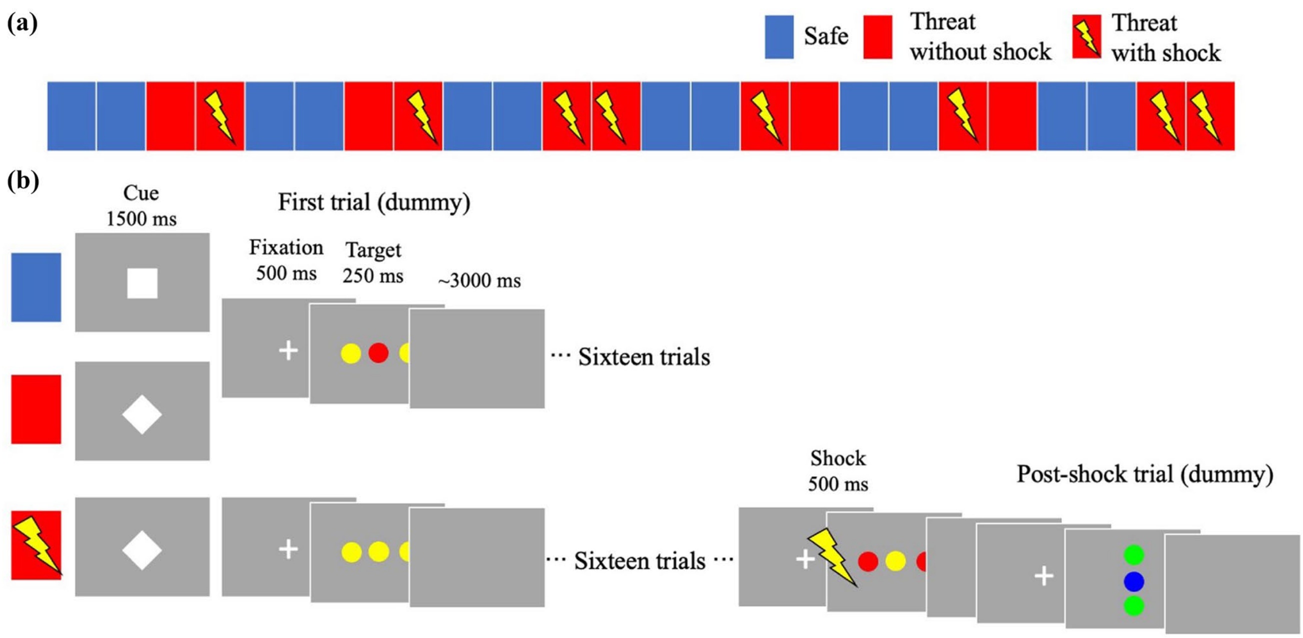

Fig. 1 An example of the task procedure. **a** The sequence of blocks; two safe and two threatening blocks were presented alternatively. An electric shock was administered in 66% of the threatening blocks. **b** Examples of trial sequence in the flanker-compatibility task in safe context and threatening context with and without the shock

shocks in blocks preceded by the threat cue. Shocks were delivered in 8 out of 12 threatening blocks. To ensure that the effect caused by the threat of shock lasted throughout threatening blocks, the electric shocks were administered during the later stages of the blocks. To prevent habituation to the electric shock, participants were encouraged to report whether they had perceived the electric shocks as "highly unpleasant but not painful" and to re-adjust the intensity of the shocks if necessary during the breaks.

Each trial started with the fixation display presented for 500 ms. A target display was then presented for 250 ms. In the flanker-compatibility task, participants were required to respond to the color of the centrally presented target as quickly and accurately as possible while ignoring flanking circles. In the Simon task, participants were required to respond to the color of the target presented at the left or right side. Incorrect responses or no responses within 2000 ms from the onset of the target triggered a 500 ms feedback tone. A blank display was presented for 1000 ms before the next trial.

Trials in each block were presented in a pseudorandom order to balance the proportions of trial types—congruent trials preceded by congruent trials (cC), congruent trials preceded by incongruent trials (iC), incongruent trials preceded by congruent trials (cI), and incongruent trials preceded by incongruent trials (iI)—as a function of current trial congruency and n – 1 trial congruency. Each type of trial was presented four times in each block of trials. Since the interaction between current trial congruency and n – 1 trial congruency was the main interest, one dummy trial, which was added at the beginning of each block, was excluded from data analyses to evaluate every trial as a function of n – 1 trial congruency. Furthermore, for the threatening context, in which the actual shocks were delivered, two trials were added at the end of each block (the one in which the shock was given and the one immediately following it); these were also excluded from data analyses. As a result, the safe blocks (12 blocks) and the threatening blocks without actual shocks (4 blocks) amounted to 17 trials, and the threatening blocks with actual electric shocks (8 blocks) amounted to 19 trials. Figure 1 illustrates the sequence of blocks and the sequence of trials within each type of block.

Data preprocessing and statistical analyses

Behavioral data

The first trial of each block, error trials, and trials immediately following error trials were removed from RT analyses (13.47%). RTs shorter than 150 ms and longer than 1250 ms were excluded as RT outliers (3.74%). For the threatening context, shock administration trials and trials immediately following shock administration trials were not analyzed (3.73%) to exclude trials influenced by the physical stimulation of the electric shock and not by the threat. This resulted

Table 2 Mean RTs and PEs for each trial types in the safe and threatening contexts by each task type

	cI		cC		iI		iC	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Flanker								
Safe								
RT (ms)	671	2.18	649	2.31	655	2.18	643	2.31
PE (%)	4.48	.68	3.78	.44	4.07	.69	3.79	.44
Threat								
RT (ms)	680	4.2	662	3.99	687	4.2	657	3.99
PE (%)	3.91	.35	2.91	.27	3.4	.35	3.34	.27
Simon								
Safe								
RT (ms)	648	2.38	614	2.14	633	2.38	621	2.14
PE (%)	4.26	.31	2.79	.29	4.63	.31	3.75	.29
Threat								
RT (ms)	659	2.17	633	1.91	656	2.17	640	1.91
PE (%)	4.22	.31	2.94	.25	4.27	.31	2.35	.25

M mean, *SE* standard error, *cI* incongruent trials preceded by congruent trials, *cC* congruent trials preceded by congruent trials, *iI* incongruent trials preceded by incongruent trials, *iC* congruent trials preceded by incongruent trials

in the exclusion of 20.88% of trials from RT analyses. After data trimming, the mean correct RT and percent error (PE) were calculated for each participant as a function of current trial congruency (congruent or incongruent), n − 1 trial congruency (congruent or incongruent), and context (safe or threatening) (Table 2). ANOVAs were conducted on the mean correct RT and PE with those factors as within-subject variables and task type (flanker-compatibility or Simon) as a between-subject variable.

Personality questionnaires

Pearson correlations were calculated to examine the relationships between questionnaire scores (STAI-S and STAI-T) and the size of the CE and the CSE and thereby assess the effect of trait anxiety on the indexes of the interference effect and its adjustment. The size of the CE was calculated as the difference of the mean RTs between incongruent trials and congruent trials. The size of the CSE was calculated by subtracting the size of the CE following incongruent trials (iI–iC) from the size of the CE following congruent trials (cI–cC). The sizes of the CE and the CSE were further calculated as functions of context.

SC data

SC data were preprocessed with MATLAB R2017a. First, raw SC data were detrended and smoothed with a median filter over 40 samples (200 ms) to reduce high-frequency noise. The baseline (the mean SC over 60 s before the start of the first block) was then subtracted from the SC data to control for individual variability. The SC data were averaged for each participant as a function of context. For threatening blocks, in which the actual shock was administered, SC data ranging from shock administration to the end of the block were discarded to examine the effect of threat on SC without the physical effect of shock administration. A one-way ANOVA was conducted on the preprocessed SC data with context (safe or threatening) as a within-subject variable.

Results

RT

The main effect of context was significant, $F(1, 94) = 22.67$, $p < .001$, $MSE = 2519$, $\eta_p^2 = .19$, driven by the greater RT in the threatening context ($M = 659$ ms) than in the safe context ($M = 642$ ms). In addition, a significant CE was observed, $F(1, 94) = 128.74$, $p < .001$, $MSE = 652$, $\eta_p^2 = .58$. The mean RT was shorter on congruent trials ($M = 640$ ms) than on incongruent trials ($M = 661$ ms). The overall CSE was observed, $F(1, 94) = 7.33$, $p = .008$, $MSE = 350$, $\eta_p^2 = .07$, driven by reduced CE following incongruent trials (17 ms), compared to the effect following congruent trials (25 ms). In addition, the interaction of context and n − 1 trial congruency was significant, $F(1, 94) = 11.78$, $p < .001$, $MSE = 306$, $\eta_p^2 = .11$. Separate analyses indicated that while responses were facilitated following incongruent trials ($M = 637$ ms) compared to

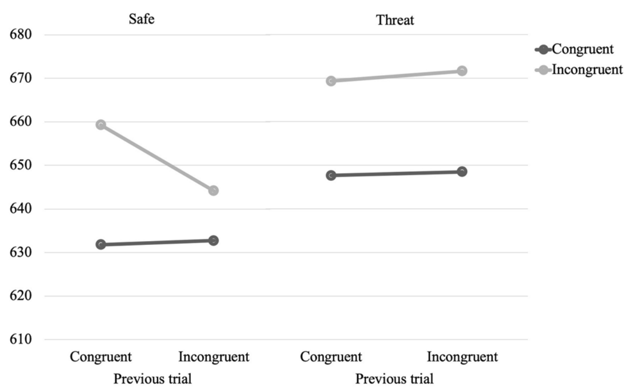

Fig. 2 Mean correct reaction times as a function of current trial congruency and n – 1 trial congruency in the safe and threatening contexts

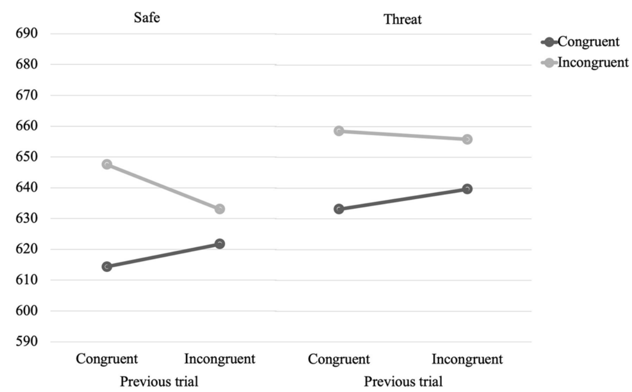

Fig. 3 Mean correct reaction times as a function of current trial congruency and n – 1 trial congruency in the safe and threatening contexts in the Simon task

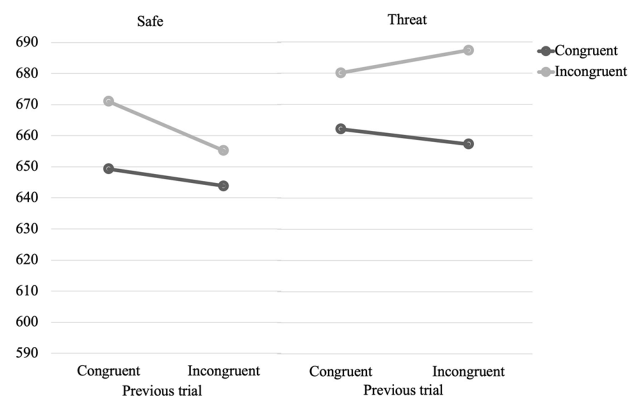

Fig. 4 Mean correct reaction times as a function of current trial congruency and n – 1 trial congruency in the safe and threatening contexts in the flanker-compatibility task

congruent trials ($M = 643$ ms) in the safe context, no comparable difference manifested in the threatening context.

More importantly, the three-way interaction of current trial congruency, n – 1 trial congruency, and context was significant, $F(1, 94) = 6.35$, $p = .01$, $MSE = 578$, $\eta_p^2 = .06$ (see Fig. 2). Separate analyses showed that the interaction of current trial congruency and n – 1 trial congruency was significant in the safe context, $F(1, 9) = 11.97$, $p < .001$, $MSE = 517$, $\eta_p^2 = .11$, driven by reduced CE following incongruent trials (11 ms), compared to congruent trials (27 ms), indicating the presence of the CSE. On the other hand, the size of the CE was similar following congruent trials (22 ms) and following incongruent trials (23 ms), resulting in no significant two-way interaction, $F(1, 9) = .11$, $p = .74$, confirming the hypothesis that the threat manipulation causes the disappearance of the CSE.

Another interest was to investigate whether the modulation of the CSE by context differs by conflict type. The four-way interaction of current trial congruency, n – 1 trial congruency, context, and task type was not significant, $F = .49$, $p = .48$. Interestingly, the three-way interaction of current trial congruency, n – 1 trial congruency, and task type was significant, $F(1, 94) = 9.28$, $p = .003$, $MSE = 350$, $\eta_p^2 = .09$. Separate two-way ANOVA analyses for each task type demonstrated that the interaction of current trial congruency and n – 1 trial congruency was significant in the Simon task, $F(1, 47) = 15.85$, $p < .001$, $MSE = 366$, $\eta_p^2 = .25$, but not in the flanker-compatibility task, $F(1, 47) = .06$, $p = .81$. In the Simon task, the CE was larger following congruent trials (29 ms), compared to incongruent trials (14 ms), indicating the presence of the CSE. On the other hand, the magnitude of the CE did not differ after congruent trials (20 ms), and after incongruent trials (21 ms), in the flanker-compatibility task.

Motivated by the idea that context may have driven the disappearance of the CSE in the flanker-compatibility task, the interaction of current trial congruency and n – 1 trial congruency was observed to examine the patterns of the sequential modulation for each task type and context. In the Simon task, the CSE was significant in safe blocks, $F(1, 47) = 11.35$, $p = .002$, $MSE = 505$, $\eta_p^2 = .19$, but not in threatening blocks, $F(1, 47) = 2.21$, $p = .14$, $MSE = 463$, $\eta_p^2 = .05$ (see Fig. 3). In the flanker-compatibility task, although the CE tended to decrease after incongruent trials (11 ms) compared to congruent trials (22 ms) in safe blocks, $F(1, 47) = 2.42$, $p = .13$, $MSE = 523$, $\eta_p^2 = .05$, the CSE was reversed in threatening blocks, $F(1, 47) = 4.8$, $p = .03$, $MSE = 366$, $\eta_p^2 = .09$, driven by increased CE following incongruent trials (30 ms) compared to following congruent trials (18 ms) (see Fig. 4).

PE

Three-way interaction of current trial congruency, n – 1 trial congruency, and context or four-way interaction with conflict type was not significant for PE, $Fs < 1$, $ps > .3$. The main effect of context was significant, $F(1, 94) = 5.15$, $p = .03$, $MSE = 10.28$, $\eta_p^2 = .05$. Participants made fewer errors in the threatening context (3.42%) than in the safe context (3.94%), indicating that there was a speed-accuracy trade-off in the threatening context. The analysis showed a significant CE, $F(1, 94) = 21$, $p < .001$, $MSE = 8.24$, $\eta_p^2 = .18$. The PE was higher on incongruent trials (4.15%) than on congruent trials (3.21%). The interaction of current trial congruency and task type was significant, $F(1, 94) = 4.51$, $p = .04$, $MSE = 8.24$, $\eta_p^2 = .05$. Separate analysis revealed that the CE was significant in the Simon task (1.39%), $F(1, 47) = 23.35$, $p < .001$, $MSE = 7.94$, $\eta_p^2 = .33$, but not in the flanker-compatibility task, (.51%), $F(1, 47) = 2.91$, $p = .09$.

Personality questionnaires

The analysis showed no significant correlation between questionnaire scores and the size of the CE or the CSE ($ps > .08$).

SC

Context had a significant effect on SC, $F(1, 95) = 33.64$, $p < .001$, $MSE = .41$, $\eta_p^2 = .26$. The mean SC was higher in the threatening context ($M = 2.47$ μS, $SD = 2.55$) than in the safe context ($M = 1.93$ μS, $SD = 2.91$), indicating that the administration of electric shocks was effective in inducing physiological arousal in the threatening context.

Discussion

In the present study, the effect of induced emotion irrelevant to task performance on cognitive control was examined by comparing the CSE between contexts with and without the threat of the electric shock. The heightened level of skin conductance in the threatening context demonstrated that the threat manipulation effectively induced physiological arousal. The overall slowing down of responses in the threatening context in comparison to the safe context suggests that the threat generally impaired performance. Most importantly, the CSE observed in the safe context was absent or reversed in the threatening context. The analysis showed this context-based CSE modulation in both the flanker-compatibility task and the Simon task. These results indicate that the threat of shock interferes with the cognitive control involved in sequential modulation regardless of the conflict type.

Unpredictability and uncontrollability of the threat interfere with task performance

Previous studies have found that processing threatening stimuli activates brain areas involved in the attentional network (Pessoa 2009, for review) and attenuates behavioral and neurological indices related to cognitive control (Choi et al. 2012; Shackman et al. 2011). More important than the level of the threat, research has suggested that unpredictability regarding threatening stimuli intensifies negative affect whereas predictable stimuli with the same threat levels ameliorate the effect of the threatening stimuli (Grillon et al. 2006; Grupe and Nitschke 2013). Similarly, a previous study showed that the controllability of stress-causing stimuli determines whether the stimuli interfere with task performance (Henderson et al. 2012). Moreover, when participants' response initiated the shock administration, the shock facilitated responses (Eder et al. 2017) in contrast with the present study's finding. In the threatening context of the present study, the administration of the electric shock occurred with some degree of unpredictability. Also, since the administration of the electric shock was not dependent on task performance, participants had little control over the electric shock. Therefore, the uncontrollability of the high-threatening electric shock likely disrupted conflict adjustment in the threatening context.

This uncontrollable nature of the electric shock could be one of factors that decreased motivation to enhance cognitive adjustment triggered by conflict. According to the original motivational account, efforts are withdrawn when success appears unlikely or not worthwhile even after mobilizing additional efforts (Kahneman 1973). Indicating that the motivational account also applies to conflict resolution, van Steenbergen et al. (2015) found an inverted U-shape relationship between task demands and the amount of the sequential modulation; the CSE disappeared or even reversed at high levels of perceived difficulty. They interpreted this as evidence that, although the difficulty imposed by conflict triggers a conflict adjustment, participants stop exerting effort in pursuit of conflict resolution when it exceeds a critical threshold. In a similar manner, decreased motivation to enhance conflict resolution due to the uncontrollability of the electric shocks presumably drove the disappearance and reversal of the CSE in the threatening context.

However, some degree of controllability and predictability existed in the way the electric shock was given. For example, participants were able to adjust the intensity of the electric shock before performing the tasks. Additionally, even though the probability of receiving electric shocks in the threatening block was random, the electric shock was administered at a later part of the blocks. While the threatening cue might have caused a phasic induction of negative mood during the initial stages of the blocks, participants may have become aware that they would not receive the electric shock until a later stage of the block. However, according to the definition by previous studies, uncontrollability arises when individual performance does not change the probability of an aversive event (Grupe and Nitschke 2013; Seligman 1975). Moreover, previous research has demonstrated that the uncontrollability or unpredictability of the threatening stimulus has a larger impact on participants' negative affect than the intensity of the threatening stimulus (Shankman et al. 2011). Therefore, even though participants were able to control the intensity of the electric shock and might have been aware of the timing of the electric shock, the non-contingency between participants' performance and the occurrence of electric shock likely caused participants to feel a lack of control over the aversive stimuli.

The effect of threat does not differ by conflict type

In contrast to the conjectures expressed in earlier studies, the analyses in this study showed a similar pattern in the modulation of the CSE by the threat of shock in both the stimulus-based conflict and response-based conflict tasks. Specifically, based on the null finding of affective modulation, researchers have previously suggested that affective modulation may be present only in stimulus-based conflict tasks, not in response-based conflict tasks (Dignath et al. 2017; Stürmer et al. 2011). On the other hand, other studies have found affective modulation of the CSE in the Simon task (Fischer et al. 2018; Plessow et al. 2011). One possible explanation is that the former studies used phasic stimuli (i.e., high arousing emotional pictures in between trials) which tends to be intense and transient (Zeng et al. 2017) whereas the latter studies induced emotion in a sustained manner as in the present study. When emotion is induced in a phasic manner, the effect of affective contents may diminish quickly and therefore not influence subsequent trials (Fritz and Dreisbach 2015; Yang and Pourtois 2018). Supporting this conjecture, Yang and Pourtois (2018) found that negative emotion enhanced CSE when the temporal duration between task stimuli and emotion-inducing stimuli (i.e., inter-trial-interval) was short but not when it was long. In such a scenario, conflict-type is irrelevant but the timing of the presentation of emotional stimuli plays a critical role in determining whether negative affect modulates the CSE. On the other hand, the temporal dynamics of conflict resolution in the flanker-compatibility task and the Simon task may explain the different interactions with emotional stimuli. For instance, previous studies have shown that conflict induction and resolution took longer in the flanker-compatibility task than in the Simon task (Mansfield et al. 2013). The temporal overlap between conflict resolution and the processing of emotional stimuli may intensify the effect of emotion on subsequent trials in the flanker-compatibility task. Future studies should clarify how the temporal dynamics of conflict resolution as well as the timing of emotion-inducing stimuli interact with each other to affect cognitive control on subsequent trials.

The absence of individual difference

Lastly, the analyses found no relationship between participants' anxiety scores and the CE and the CSE in both threatening and safe contexts. Given previous findings regarding the relationship between trait anxiety and distractor interference (Bishop 2009) or the CSE (Osinsky et al. 2010, 2012), the absence of any relationship is perplexing. One possible explanation is that the presence of the contrasting context eliminated the potential effect of individual difference on performance in the present study. Specifically, electric shock's effectiveness in inducing negative emotion in both low- and high-trait anxious individuals in the threatening context could have nullified any trait anxiety-based differences. In the safe context, having experienced the threatening context, participants might have been less anxious in the safe context irrespective of their anxiety levels. In our previous study (Jeong and Cho 2019), the negative relationship between trait anxiety and the size of the CSE, which was observed when participants experienced the safe context alone, disappeared when the participants were exposed to both safe and threatening contexts.

Conclusion

In conclusion, the present study builds on findings illustrating the intimate relationship between emotion and the CSE. The results indicate that a task-irrelevant stimulus with a high threat level caused the disappearance of the sequential modulation through the deprivation of resources and/or motivation to enhance cognitive control upon the detection of conflict. These findings shed light on the factors that may enhance or impair the impact of emotion on the CSE and thus help bridge the gap between previous discrepant findings.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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