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Impaired cognitive control during reward pursuit and punishment avoidance

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Abstract

Two experiments were conducted to examine how cognitive control is modulated by response-contingent reward (Experiment 1) and response-contingent punishment (Experiment 2). The congruency sequence effect (CSE), which is the reduction of the congruency effect after incongruent trials compared to the effect after congruent trials, was analyzed as an index of cognitive control. In both experiments, response speed and accuracy were enhanced by reward or punishment. However, in Experiment 1, the CSE was not evident during anticipation of large reward, whereas a significant CSE was obtained during anticipation of small reward. In contrast, in Experiment 2, the CSE was equivalent regardless of the magnitude of punishment. Moreover, the magnitude of the congruency effect was greater in large punishment than a small one. These results indicate a discrepancy between appetitive and aversive motivations in modulating cognitive control even though both invigorated motor responses. In appetitive motivation, cognitive control is likely to be biased toward a proactive control mode, whereas reactive control is preferable in aversive motivation, where aversiveness also interferes with cognitive processes.

Keywords Motivation · Cognitive control · Reward · Punishment · Congruency sequence effect

Introduction

Motivation is one of the critical factors in adjusting human behavior. To obtain a desired outcome, such as reward, individuals adjust their behavioral strategies so to increase the chance to earn the outcome. Consequently, motivation generates substantial differences in goal achievement, depending on whether or not an individual is motivated while performing a task. However, behaviors can be adjusted in various ways depending on what induces motivation. For example, a factory manager might try to increase a worker's productivity by providing incentives or by reducing his/her salary if his/her productivity does not meet a specified threshold. Regardless of which offer is more effective in increasing productivity, the worker would be motivated to earn a bonus or to not lose his/her salary. The former, the motivation to earn a reward, is referred to as appetitive (or approach) motivation, and the latter is aversive (or avoidance) motivation.

The impacts of appetitive motivation on cognitive processes have been investigated largely, and there is a general consensus that appetitive motivation enhances cognitive processes relevant to the task goal at hand. For instance, Savine et al. (2010) examined how motivation modulates cognitive control in the task-switching paradigm. In their Experiment 1, participants had a chance to obtain monetary incentives that were provided after fast and correct responses in a reward condition. In a control condition, participants did not receive an incentive, regardless of their task performance. The results showed that the switching costs, which are an index of cognitive control (Rogers and Monsell 1995), were reduced in the reward condition compared to the control condition, indicating that cognitive control was enhanced by the motivation to earn reward. The beneficial effect of the response-contingent reward was also observed in working memory (Jimura et al. 2010) and response conflict tasks (Krebs et al. 2010; Padmala and Pessoa 2011). Collectively, behavioral evidence indicates that motivated states to obtain rewards enhance cognitive performance by focusing on the task-relevant processes and setting the cognitive system

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ready for the upcoming task, which is related to obtaining the reward (Braver 2012; Dreisbach and Fröber 2019; Pessoa 2009).

The impact of aversive motivation on cognitive control also can be accounted for by the explanations for the appetitive motivation. The aversive motivation would sharpen cognitive processes in preparation for avoiding punishment. Thus, cognitive control is enhanced with aversive motivation. This explanation would be valid based on the idea that the successful avoidance of punishment is comparable with collecting reward (Kim et al. 2006). In instrumental conditioning, for example, a rat can learn to press a lever by obtaining food (reward) after the behavior. The lever-pressing also can be learned if the behavior releases the rat from electric shocks (punishment). A human brain imaging study has also shown that the neural responses in the medial orbitofrontal cortex, which is responsible for encoding reward values, increased not only when reward was received but also when punishment was successfully avoided (Kim et al. 2006).

However, these similarities between reward collection and punishment avoidance do not necessarily imply that avoiding punishment motivates individuals in a similar way to pursuing reward. Even though individuals experience hedonic emotion after the successful avoidance of punishment, the mental states for avoiding punishment would not be analogous with those during reward expectation. According to Berridge and Robinson (2003), reward has multiple components; liking, wanting, and learning. “Liking” is a reaction to reward salience during consuming reward. “Wanting” is a motivation of reward salience, occurring before consuming reward. “Learning” is the associations between reward and behavior, occurring throughout a repetitive sequence of reward and behavior. The reward components are not only separable in terms of psychological notions, but also in the neural mechanisms mediating psychological processes and behaviors. In an analogy with the suggestion of Berridge and Robinson, the motivation to avoid punishment is different from the hedonic experience after successful avoidance of punishment. That is, it cannot be assured that “wanting” to avoid punishment motivates individuals in the same way of “wanting” to earn reward, even if the successful avoidance of punishment is as “likable” as reward collection. Indeed, evidence from behavioral studies showed that the aversive motivation to avoid punishment modulates memory in a different way compared to the appetitive motivation to earn reward. For instance, Murty et al. (2011) showed that declarative long-term memory was impaired when participants were avoiding electric shocks but it was enhanced when they were pursuing monetary incentives. Similarly, working memory performance was improved when a sweet juice was provided after correct responses compared to when a tasteless liquid was provided, but no difference was obtained regardless of whether salty water or tasteless liquid was provided (Savine et al. 2010).

Motivation and cognitive control

If the impact of motivation is limited to the increase in processing resources or energy, energization would only result in behavioral invigoration. In the performance of a cognitive task other than a simple response task requiring swift responses, it is necessary to recruit multiple cognitive processes and coordinate these processes depending on intentions and situational demands, such as pursuing reward. The dual mechanisms of control (DMC) model postulates that cognitive control is recruited either proactively or reactively (Braver 2012). The proactive control mode enables individuals to maintain goal-directed behaviors and optimizes cognitive processes to prepare up-coming events. If conflict between the task-relevant and task-irrelevant information is anticipated, cognitive control is proactively engaged to configure an information processing system to manage the anticipated conflict while maintaining the goal-directed behaviors. On the other hand, the reactive control mode is the “on-demand” adjustment of cognitive control. In the reactive mode, cognitive control reconfigures the system reacting to a situation, such as experiencing conflict, thereby enhancing cognitive performance on a subsequent conflict trial. For instance, in congruency tasks, such as the Stroop and Simon tasks, cognitive control processes related to conflict are more likely to be enhanced after experiencing conflict, resulting in a smaller congruency effect after incongruent trials compared to the effect after congruent trials (e.g., Duthoo and Notebaert 2012). This reduction of the congruency effect is referred as the congruency sequence effect (CSE).

The interaction of cognitive control with appetitive and aversive motivations is well captured in the DMC model. If individuals expect to obtain reward by performing a task successfully, they would recruit the goal-directed control in advance and keep the level of cognitive control high to increase the probability of earning reward. Thus, when reward is expected, cognitive control relies on the proactive mode which is supposed to be observed in sustained activities of lateral prefrontal cortex (Jimura et al. 2010). On the other hand, punishment is hypothesized to bias cognitive control toward the reactive mode. In their fMRI study, Braver et al. (2009) had participants perform a cognitive task, AX-CPT, which examines proactive and reactive controls depending on the relationship between cue and target types. The results showed that BOLD responses in the dorsolateral prefrontal cortex (dlPFC) were maintained at a high level during reward anticipation. However, the tonic responses in the dlPFC shifted in a transient fashion during punishment anticipation. Based on these observations, Braver et al. suggested that punishment shifts cognitive control from a proactive mode to a reactive one. Although the two control modes are not exclusive of one another, one of the control modes is preferential over the other depending on a given situation, such as pursing reward or avoiding punishment (Westbrook and Braver 2016).

It has been attempted to investigate the differential influences of reward and punishment on the CSE (Braem et al. 2013a, b; Stürmer et al. 2011; van Steenbergen et al. 2009). However, these studies focused on the effects of the receptions of reward and punishment, not the effects of the prospects of reward and punishment. The receptions of reward and punishment might reinforce behaviors and associate the behaviors with their outcomes (reward or punishment), whereas the prospects of reward and punishment motivate individuals to obtain a reward and to avoid a punishment (Berridge and Robinson 2003).

Regarding the prospective reward and punishment, to our best knowledge, only a few studies investigated the motivational influences of reward and punishment on the CSE. The primary interest in the interaction between motivation and CSE was mainly focused on the impact of appetitive motivation induced by reward prospect. Even though manipulating the punishment prospect in some studies, the impact of punishment prospects was not differentiated from that of reward prospect (e.g., Soutschek et al. 2014; Yamaguchi and Nishimura 2018). For instance, in Soutschek et al. (2014), participants were motivated to perform a Stroop task quickly and accurately to receive monetary incentives and not to lose these incentives in a high motivation condition. In a low motivation condition, however, monetary incentives were not provided regardless of task performance. In their Experiment 1, cognitive control was measured by the CSE, which has been suggested to reflect reactive control after experiencing conflict (Botvinick et al. 2001; Duthoo and Notebaert 2012). Parallel to the prediction of the DMC model, Soutschek et al. hypothesized that the anticipation of monetary incentives would reduce the magnitude of the CSE because cognitive control would be biased against the reactive mode during reward anticipation. However, they found no evidence showing that the prospect of reward modulated the magnitude of the CSE, even though the mean response time (RT) and the magnitude of the Stroop effect were decreased in the high motivation compared to the low motivation condition. Based on these results, Soutschek et al. suggested that reactive control is independent of the control mechanism triggered by motivation.

However, in Soutschek et al.'s (2014) study, participants did not only accumulate monetary incentives after fast and correct responses, but also they lost some of the total incentive if a response was not fast enough or incorrect. That is, participants anticipated punishment as well as reward in a motivation condition. When both reward and punishment are potentiated at the same time, the incentive values of them could be integrated into a motivational valence to modulate cognitive control (Yee et al. 2016). Moreover, considering that the cognitive system is more likely to rely on the reactive control mode when punishment is anticipated (Braver et al. 2009), cognitive control might have been operated reactively in some trials if participants have perceived punishment more saliently than reward on those trials. Consequently, the reliance on the proactive control mode could not have been enough to reveal the CSE modulation by motivation in Soutschek et al.'s experiment.

The present study

Two experiments were conducted to investigate the modulation of cognitive control by appetitive and aversive motivation, independently. Motivation was induced by providing participants with a chance to win or to not lose monetary incentives based on their task performance. A large or small amount of monetary incentive was awarded for each fast and correct response in Experiment 1 and a large or small amount was deducted from the total amount of monetary incentive for each slow or incorrect response in Experiment 2. Thus, in both experiments, participants were required to make a response rapidly and correctly to maximize the monetary incentives. The only difference between the two experiments was the valence of expected outcome, which was positive in Experiment 1 and negative in Experiment 2.

If reward and punishment trials are intermixed in an experiment, the punishment is a reduction of accumulated rewards. However, it is not an effective punishment in most cases because the net balance of monetary gains (reward) and losses (punishment) would be nevertheless positive throughout the experiment. For example, if a participant performs a task successfully on 80% of reward and punishment trials equally, the probability of losing incentives is 20% on punishment trials, which is lower than the probability of earning incentives on reward trials (80%). In the situation where the total amount of incentives is positively accumulating, the motivational states to avoid punishment would not be induced effectively in the punishment condition. Accordingly, reward and punishment were manipulated in separate experiments.

As a behavioral index of cognitive control, a Simon task was used in both experiments. In congruency tasks, such as Stroop and Simon tasks, task-relevant and task-irrelevant target features activate response codes independently. For instance, in the Simon task, participants are instructed to make a left or right response to a non-spatial target feature, such as color. The target is presented to the left or right of fixation. If the target location does not match with the response location (e.g. the right response to the red target presented to the left of fixation), this spatial mismatch generates conflict, which is called the congruency effect (CE) broadly. The amount of the CE is smaller in the trials preceded by a mismatch trial (i.e. incongruent trial) than the trials preceded by a congruent trial. This reduction of the CE, or the CSE is considered reflecting the involvement of reactive cognitive control (Botvinick et al. 2001; Duthoo and Notebaert 2012).

In sum, the aim of the present study was twofold. First, the impact of appetitive motivation on the CSE was investigated. If appetitive motivation enhances cognitive control in general, reactive control to adjust cognitive processes after conflict would be facilitated, resulting in a greater CSE in response to a large rather than a small reward. However, if reward anticipation increases the reliance on proactive control, reactive control would be less influential, resulting in a smaller CSE in response to a large compared to a small reward. Second, the impact of aversive motivation on cognitive control was examined. If the impact of aversive motivation on cognitive control is comparable to that of appetitive motivation, the CSE modulation by aversive motivation would be similar to the CSE modulation by appetitive motivation. However, if aversive motivation is distinct from appetitive motivation in terms of the impact on cognitive control, a different pattern of the CSE modulation by aversive motivation would be obtained.

Experiment 1

The purpose of Experiment 1 was to examine how appetitive motivation affects cognitive control. In the experiment, participants were instructed to perform two Simon tasks (Simon 1969). In a typical Simon task, one of two target colors is presented to the left or right of a fixation point, and participants are required to press a left or right button depending on the target color, regardless of its location. However, in a two-forced choice task, repetitions of stimulus- and response-related features are inevitable, which are confounded with the sequential modulation of the CE by the congruency of the previous trial (Hommel et al. 2004; Mayr et al. 2003). To avoid the repetitions of stimulus- and response-related features across consecutive trials, two sets of two target colors were used (e.g. Kim and Cho 2014). One set was composed of yellow and green and the other was red and blue. Each set of the target colors was presented alternatively in a trial-by-trial manner. For instance, if a yellow or green target was presented in a trial, either red or blue was presented in the next trial.

The CSE is an across-trial measure, which could be contaminated by a stimulus presentation between trials, such as reward cue and feedback. To avoid such contamination, the appetitive motivation was manipulated in a blocked fashion. A cue was presented to inform participants of the amount of reward for each correct response at the beginning of each block, and a reward feedback showing the amounts of reward accumulated during the block and the experiment was presented at the end of each block. To earn monetary incentives, participants were required to make a correct response before the target disappeared. The target duration was determined individually by using staircase procedures during a practice session without reward. Each successful response was worth 2 KRW (about 0.002 USD) in the small reward blocks, and 20 KRW (about 0.02 USD) in the large reward blocks. Although it is typical to offer no reward on control trials in human reward studies, no reward after successful task performance might demotivate participants to perform the task. Thus, we provided a minimal amount of monetary incentives for each successful response in the control condition. The maximum amount of incentive that each participant could earn in an experiment was limited to 3000 KRW (about 3 USD).

Cognitive control was indexed with the CSE, which was the difference between the CE after incongruent trials and the effect after congruent trials. If appetitive motivation improves cognitive control in general, the cognitive control adjusting conflict would be enhanced as well. Consequently, the CSE would be greater in large reward blocks than small reward blocks. However, according to the DMC model, reward expectation leads participants to recruit cognitive control proactively (Braver 2012; Jimura et al. 2010). Although it is supposed that proactive control is independent from reactive control, the increased reliance on the proactive control during reward anticipation can attenuate the influence of the reactive control mode on task performance (Westbrook and Braver 2016). Thus, if the appetitive motivation to obtain monetary incentive prioritizes the proactive control mode, the CSE, which is an outcome of the reactive adjustment of conflict, would be reduced in large reward than small reward blocks.

Methods

Participants

To detect the difference in the CSE depending on a motivation level with a power $1\text{-}\beta = 0.95$ at an $\alpha = 0.05$, a power analysis using G*Power 3.1 (Faul et al. 2009) for repeated-measures analyses of variance (ANOVAs), as a function of Reward, Previous Congruency, and Current Congruency, required 25 participants, assuming the effect size as $\eta^2_p = 0.375$ based on a similar experiment by Soutschek et al. (2014, Experiment 2). Given a possible difference in the effect-size estimation for the CSE, a larger number of participants were recruited. Consequently, thirty-two participants (13 males; age range: 19–26 years old, $M = 21.7$) were recruited via a community webpage for Korea University students. They gave informed written consent, and the study was approved by the Institutional Review Board of Korea University (1040548-KU-IRB-15-31-A-1). According to self-report, participants did not either currently have, or a history of having, any psychiatric or neurological diseases. They also had normal color vision and normal or corrected-to-normal visual acuity. They were compensated 4000 KRW (about 4 USD) for their participation.

Personality questionnaires

Prior to the experiment, participants completed the standardized Korean version of BIS/BAS scales (Kim and Kim 2001). However, we did not report the results related to these scales because none showed any meaningful relationship with the data (Pearson's rs < 0.31, ps > 0.095).

Stimuli and apparatus

The presentation of visual stimuli and the recording of participant's behavioral responses were controlled by Psychophysics Toolbox Version 3 (https://www.psychtoolbox.org/) implemented in MATLAB 2008a (The MathWorks, Natick, MA). Responses were collected using a standard computer keyboard.

The fixation point was a white crosshair (0.7° × 0.7°) presented at the center of the computer screen. The target stimulus was a square (1.7° × 1.7°) filled in green, red, yellow, or blue ([0, 150, 0], [255, 0, 0], [255, 255, 0], or [0, 0, 255] in RGB color space, respectively). The target was presented to the left or right of the fixation point. The center-to-center distance between the fixation and the target was 4.4°. At the beginning of each block, a written message, "작은 보상" ("small reward" in Korean; 7.8° × 1.7°) or "큰 보상" ("large reward" in Korean; 5.8° × 1.7°) was presented to inform participants the amount of reward for each correct response in that block. Along with the block cue, horizontal or vertical bars were displayed in white to remind participants of the block type (small or large reward block; counter-balanced). The length of the horizontal bars was 27.8° and placed 10.6° above and below the fixation point. The length of the vertical bars was 21.0° and placed 14.1° left and right of the fixation. The horizontal or vertical bars remained on the screen during each block. All stimuli were presented on a black background with a 17-inch CRT monitor. The distance between participants and the monitor was approximately 60 cm.

Procedure

After paper forms were completed, including the BIS/BAS questionnaire and the provision of written consent, the experiment started with a practice session. The practice session had two purposes: (1) to familiarize the participants with the task, and (2) to calibrate the RT threshold for reward. During the practice session, neither reward feedback nor actual reward was provided. After the practice, participants had a short warm-up session, in which reward feedback was displayed at the end of each block. The warm-up session aimed to provide experience for participants on how the experiment would proceed with reward feedback. Thus, actual reward was not provided. The main session immediately followed the warm-up session.

In the practice session, each participant completed 97 trials. The first trial served as a dummy trial to generate the "previous congruency" of the following trial. With consideration of the previous congruency (congruent or incongruent), there were four trial types, congruent trials after a congruent (cC), congruent trials after an incongruent (iC), incongruent trials after a congruent (cI), and incongruent trials after an incongruent (iI). The order of trials was pseudorandomly predetermined to equate the numbers of all trial types.

At the beginning of each trial, the fixation point was presented for 500 ms followed by a target display. In the target display, a square filled in a target color was presented to the left or right of the fixation point. Participants were instructed to press the "d" key to the green target square with their left middle finger, the "f" key to the red one with their left index finger, the "j" key to the yellow one with their right index finger, and the "k" key to the blue one with their right middle finger before the target disappearance. The red or yellow target was presented in odd trials of each block and the green or blue target was in even trials to avoid repetition.

The target duration was adjusted dynamically during the practice session by using a staircase procedure, which was applied independently to the four trial types (cC, cI, iC, and iI). Participants were unaware of the staircase procedure. If a single speed criterion was shared across trial types that have different mean RTs (e.g. congruent and incongruent trials), the probability of obtaining reward would be unequal across them, possibly resulting in uneven motivation levels. Accordingly, four different speed criteria were set for each participant to maintain the reward rates similar across the trial types. Note that the staircase procedures were independent of reward manipulation. For example, the speed criterion on iI trials was identical for both small and large reward blocks. Thereby, any behavioral changes in large relative to small reward blocks can be attributed to the reward manipulation. The initial target duration for each trial type in the practice session was 748 ms. If a response was made correctly before target disappearance on successive two trials of the very same trial-type, the target duration decreased by 34-ms on a subsequent trial of the same trial-type. If a participant failed to respond correctly or rapidly before target disappearance in a trial, the target duration increased by 34-ms on a subsequent trial of the same trial-type (two-down/one-up). The 70th percentile of the last ten correct trials of each trial-type was used for the target duration in the main session.

After 1500 ms from the target presentation, a feedback display was presented for 500 ms, followed by a blank screen for 500 ms as an inter-trial interval. The feedback informed participants that their response was too slow by showing a written message of "늦었습니다" ("too slow" in Korean) if a response was made after the target disappearance, or "틀렸습니다" ("wrong" in Korean) if they made an incorrect response. For correct and rapid responses, no feedback was presented.

The main session consisted of 32 blocks, including sixteen small reward blocks (2 KRW per each correct and rapid response) and sixteen large reward blocks (20 KRW per each correct and rapid response). The order of reward blocks was pseudo-randomly predetermined. Each block consisted of nine trials, including two trials for each trial type (cC, cI, iC, and iI) and the first trial of each block, which was a dummy trial to generate the previous congruency for the second trial. Thus, the first trials in each block were excluded from the analyses. Each block started with a block cue for 1000 ms followed by a 1000-ms blank screen. At the end of each block, reward feedback was presented for 1000 ms, displaying the amount of reward earned during the block and the total amount of reward accumulated to that point (Fig. 1). In total, each participant performed 288 trials (256 trials were used for analysis), resulting in 36 trials per each trial type (32 trials for analyses) in the Simon task.

The trial sequence was identical to that of the practice session, except that there was no feedback for slow or wrong responses. The target durations were predetermined for each participant based on his/her task performance during the practice session.

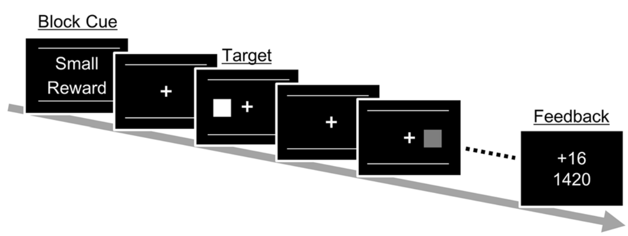

Fig. 1 Example of the trial sequences in Experiments 1 and 2. The target stimulus was presented in one of four colors. The feedback at the end of each block displayed how much incentives the participant obtained (Experiment 1) or lost (Experiment 2) in the block along with the total amount of incentives he/she has at the moment

Results

For percent error (PE) and RT analyses, the first trials in each block and the trials following incorrect trials were not included in any analyses. Additionally, the trials with a RT longer than three standard deviations from the condition-specific mean of each participant were excluded (mean 0.41% of the total trials across all participants). Note that the trials with responses after target disappearance (i.e. unrewarded trials) were not excluded from analyses because we were interested in the responses to win reward, and not the rewarded responses. For the RT analyses, incorrect trials were removed.

Mean PE and RT data were calculated for each participant as a function of Reward (small, large), Previous Congruency (c, i), and Current Congruency (C, I). Repeated-measures analyses of variance (ANOVAs) were conducted on the mean RT and PE data with those variables as within-subject factors. The CSE was calculated by subtracting the magnitude of the CE after incongruent trials from the magnitude of the CE after congruent trials (i.e.[cI − cC] − [iI − iC]). Descriptive statistics of the behavioral data are summarized in Table 1. All data can be found on the Open Science Framework (OSF) at https://osf.io/yn94h.

Table 1 Descriptive statistics of behavioral data in Experiment 1

	Small reward		Large reward	
	c	i	c	i
RT				
C	466 (±17.8)	476 (±20.1)	452 (±16.5)	449 (±17.0)
I	500 (±18.1)	482 (±17.9)	477 (±15.0)	466 (±17.5)
Congruency effect	34	6	25	17
PE				
C	10.05 (±2.82)	11.23 (±2.81)	7.71 (±1.70)	7.51 (±2.02)
I	14.36 (±3.00)	11.98 (±2.66)	11.11 (±2.61)	8.52 (±2.02)
Congruency effect	4.30	0.75	3.41	1.01

Mean-centered 95% confidence intervals are in brackets. *C* congruent in current trial, *I* incongruent in current trial, *c* congruent in previous trial, *i* incongruent in previous trial

Reward collection rates

To verify reward manipulation, reward collection rates were calculated for each participant by dividing the number of successful trials with correct and fast responses by the total number of trials as a function of Reward, Previous Congruency, and Current Congruency. As results, participants received rewards on 80.69% of the small reward trials and 85.52% of the large reward trials in the main session, $F(1, 31) = 39.12$, $p < 0.001$, $MSe = 38.23$, $\eta_p^2 = 0.56$. The reward collection rates were higher on congruent (86.43%) than incongruent trials (79.79%), suggesting that it was more difficult to meet the speed criterion on incongruent than congruent trials even with different speed criteria for different trial sequence types, $F(1, 31) = 20.93$, $p < 0.001$, $MSe = 134.83$, $\eta_p^2 = 0.40$. Importantly, however, the interaction of Previous Congruency and Current Congruency was not significant, $F(1, 31) = 2.74$, $p = 0.108$, $MSe = 117.80$. Also, it did not interact with Reward, $F(1, 31) = 0.46$, $p = 0.503$, $MSe = 56.03$. These results provide no evidence that the difficulties in obtaining reward were different across trial types and reward size. No other main or interaction effect was observed, $Fs(1, 31) < 2.97$, $ps > 0.095$.

RT

The main effect of Current Congruency was significant, $F(1, 31) = 45.34$, $p < 0.001$, $MSe = 574$, $\eta_p^2 = 0.59$, indicating a significant CE (*M*s = 461 and 481 ms on the congruent and incongruent trials, respectively). RT was also modulated by Previous Congruency, $F(1, 31) = 4.46$, $p = 0.043$, $MSe = 405$, $\eta_p^2 = 0.13$. The mean RT was shorter after incongruent trials ($M = 468$ ms) than after congruent trials ($M = 474$ ms). Current Congruency interacted with Previous Congruency, $F(1, 31) = 19.81$, $p < 0.001$, $MSe = 257$, $\eta_p^2 = 0.39$, replicating the CSE. The CE was smaller after incongruent trials (11 ms), $t(31) = 3.18$, $p = 0.003$, than after congruent trials (29 ms), $t(31) = 7.94$, $p < 0.001$.

The main effect of Reward was also significant, $F(1, 31) = 60.14$, $p < 0.001$, $MSe = 427$, $\eta_p^2 = 0.66$. Mean RT was shorter in large reward blocks ($M = 461$ ms) than small reward blocks ($M = 481$ ms), showing that the large reward motivated participants to respond more vigorously than the small reward did. However, Reward interacted with neither Previous Congruency, $F(1, 31) = 0.63$, $p = 0.432$, $MSe = 294$, $\eta_p^2 = 0.02$, nor Current Congruency, $F(1, 31) = 0.03$, $p = 0.870$, $MSe = 320$, $\eta_p^2 < 0.01$.

Importantly, a significant three-way interaction of Previous Congruency, Current Congruency, and Reward was obtained, $F(1, 31) = 5.92$, $p = 0.021$, $MSe = 264$, $\eta_p^2 = 0.16$. In small reward blocks, the magnitude of the CE was reduced after incongruent trials (6 ms) compared to after congruent trials (34 ms), showing an evident CSE (28 ms), $F(1, 31) = 18.75$, $p < 0.001$, $MSe = 328$, $\eta_p^2 = 0.38$. However, in large reward blocks, it was not statistically significant (CSE = 8 ms), $F(1, 31) = 2.61$, $p = 0.116$, $MSe = 193$, $\eta_p^2 = 0.08$.

PE

The main effect of Current Congruency was significant, $F(1, 31) = 9.41$, $p = 0.004$, $MSe = 38.11$, $\eta_p^2 = 0.23$, as found for the RT data (9.13% and 11.49% on congruent and incongruent trials, respectively). Previous Congruency did not show a main effect, $F(1, 31) = 1.62$, $p = 0.213$, $MSe = 39.30$, $\eta_p^2 = 0.05$, but interacted with Current Congruency, $F(1, 31) = 4.48$, $p = 0.043$, $MSe = 31.62$, $\eta_p^2 = 0.13$, indicating a significant CSE. A robust CE was observed after congruent trials (3.86%), $t(31) = 3.35$, $p = 0.002$, but not after incongruent trials (0.88%), $t(31) = 0.95$, $p = 0.350$.

The main effect of Reward was significant, $F(1, 31) = 22.14$, $p < 0.001$, $MSe = 29.49$, $\eta_p^2 = 0.42$. Participants committed less errors in large reward blocks (8.71%) than small reward blocks (11.91%), showing that the large reward motivated participants to respond more accurately than the small reward. However, Reward interacted with neither Previous Congruency, $F(1, 31) = 0.69$, $p = 0.414$, $MSe = 15.00$, nor Current Congruency, $F(1, 31) = 0.09$, $p = 0.771$, $MSe = 18.93$. The three-way interaction of Reward, Previous Congruency, and Current Congruency was not significant, $F(1, 31) = 0.10$, $p = 0.755$, $MSe = 53.94$.

Discussion

We found no evidence indicating that reward decreased the size of the CE, which has been demonstrated in previous studies (Krebs et al. 2010; Padmala and Pessoa 2011; Soutschek et al. 2014). In those studies, however, the reward effect was examined by comparing task performance in reward and no-reward conditions, whereas in the present study, the effect was compared between large and small reward conditions. Even though the motivation level was supposed to be minimal in the small reward blocks, some participants could have been motivated substantially. If so, the difference in motivation levels of the small and large reward blocks would have been too small to detect the reward modulation on the CE. Another possibility is that the blocked design of reward manipulation undermined the reward effect. In the blocked design, it is assumed that a reward cue motivates participants and a reward feedback reinforces successful performance. However, because a reward cue was presented only at the beginning of each block, it is possible that the impact of the reward cue was diminished throughout the block. Additionally, because a reward feedback was presented at the end of the block, the delayed feedback could have discounted the value of reward (Frederick et al. 2002).

Nevertheless, it was evident that reward modulated the CSE. The CSE was not observed in the large reward blocks while it was robust in the small reward blocks. The prospect of reward is supposed to promote the proactive control mode relative to the reactive control mode (Braver 2012). Although proactive and reactive controls are independent from each other, reactive control may play a limited role in controlling cognitive processes when proactive control is prioritized during reward anticipation (Westbrook and Braver 2016). Considering that the CSE was supposed to indicate the engagement of reactive control (Botvinick et al. 2001; Duthoo and Notebaert 2012), the lack of the CSE in the large reward blocks reflected that reactive control was less likely to have been engaged during the adjustment of conflict.

One might argue that a negative mood was induced in small reward blocks because the less-gain was evaluated as a negative outcome compared to the large reward. If so, the larger CSE in small reward than the large reward blocks would be attributed to the negative mood induced by the prospect of the less-gain (Dreisbach and Fischer 2015; van Steenbergen et al. 2010; Yang and Pourtois 2018). However, relatively negative evaluation does not necessarily imply that the small reward induced a negative mood. For instance, in their Experiment 2, Larsen and Norris (2009) had participants evaluate the valence of pictures in the context where emotionally mild pictures were presented on most trials and the context where emotionally extreme pictures were the majority. The participants' evaluation ratings for the moderately pleasant pictures were less pleasant in the extreme context than the mild context. However, the rating scores for the moderately pleasant pictures in the extreme context were still higher than the rating scores for the mildly pleasant pictures. These results suggest that a pleasant stimulus would not be evaluated negatively even though the pleasantness of stimulus (e.g., small reward) is evaluated relative to other stimuli (e.g., large reward). On the other hand, if no reward is provided in some trials while a substantial amount of reward is given in other trials, it is possible that the omission of reward functions as punishment reception (e.g., Kim et al. 2006). However, in the present study, we provided a minimal amount of monetary incentives instead of no-incentives in the blocks for the "baseline condition", to prevent participants from any negative mood or demotivation. Thus, it is reasonable to assume that the minimal incentives modulated cognitive processes with a mildly positive mood rather than a negative mood.

The results are inconsistent with the results of Soutschek et al. (2014), in which no evidence of the interaction between the CSE and motivation was found. One possible reason for the lack of this interaction could be that participants in their experiment were motivated not only to earn a reward, but also to avoid punishment. Reward and punishment have an antagonistic relationship with each other in terms of emotional valence (Burgdorf and Panksepp 2006; Davis and Whalen 2001; Lang and Bradley 2010). In addition, it has been suggested that a preferred control mode varies depending on whether reward or punishment is anticipated (Westbrook and Braver 2016). In a circumstance where either reward or punishment is provided, cognitive control can be biased toward a proactive mode on some trials but biased toward a reactive mode on other trials. Thus, it is plausible that, in Soutschek et al. the impact of reward anticipation on the CSE was diluted with the impact of punishment anticipation, resulting in the null finding of the interaction between motivation and the CSE.

Experiment 2

It is widely accepted that motivation enhances cognitive processes by allocating more processing resources (Pessoa 2009), by adjusting cognitive control proactively (Braver 2012), and by shielding goals from distraction (Dreisbach and Fröber 2019). Given that successful avoidance of punishment is rewarding (Kim et al. 2006), it can be assumed that the aversive motivation to avoid punishment is similar to the appetitive motivation to earn reward. However, aversive and appetitive motivations might have different effects on cognitive processes because a specific emotion would be evoked depending on the valence of the outcome (Burgdorf and Panksepp 2006; Davis and Whalen 2001; Eysenck et al. 2007; Lang and Bradley 2010). In the domain of cognitive control, it has been suggested that the impact of punishment could be different from that of reward in potentiating a cognitive control mode, such as that punishment anticipation promotes reactive control, whereas reward anticipation promotes proactive control (Braver et al. 2009). Another line of studies suggested that an aversive signal from the conflict in the previous trial could be enlarged by the averseness of punishment (Dreisbach and Fischer 2015; van Steenbergen et al. 2010; Yang and Pourtois 2018). Thus, it can be hypothesized that aversive motivation to avoid punishment would have a distinctive effect on cognitive control compared to appetitive motivation to earn reward.

To induce aversive motivation, a monetary loss by way of punishment was used in this experiment. It is unethical and practically impossible to take real money from participants. Yet, if the loss of hypothetical money (i.e. decreases of numbers on screen) is used as a punishment, it would not be effective. To make the monetary loss more realistic, we provided participants an initial endowment of 3,000 KRW (about 3 USD) with cash before starting an experiment, and participants were explicitly informed that the endowment was bonus money which could be reduced depending on his/her task performance during the experiment. If a response was slow or incorrect, 2 KRW (about 0.002 USD) was deducted from the total amount of the monetary incentive in the small punishment blocks or 20 KRW (about 0.02 USD) in the large punishment blocks.

As in Experiment 1, cognitive control was measured with the CSE. If the aversive motivation to avoid punishment modulates cognitive control by increasing the reliance on proactive control likely as the appetitive motivation to obtain reward, the magnitude of the CSE would be reduced in the large punishment blocks compared to the small punishment blocks. However, if cognitive control is biased toward the reactive control mode during punishment anticipation (Braver et al. 2009) or the aversive signal of conflict is enlarged by punishment (Dreisbach and Fischer 2015; van Steenbergen et al. 2010; Yang and Pourtois 2018), the magnitude of the CSE would be greater in large than small punishment blocks.

Methods

Participants

A new group of thirty-two participants (16 males; age range: 19–27 years old, $M = 22.1$) was recruited from the same participant pool as in Experiment 1. They gave informed written consent, and the study was approved by the Institutional Review Board of Korea University. They were compensated 4,000 KRW (about 4 USD) for their participation.

Personality questionnaires

Participants completed the standardized Korean version of BIS/BAS scales (Kim and Kim 2001), prior to the experiment. Again, we did not find any meaningful results and so these are not reported further here (Pearson's rs < 0.24, ps > 0.197).

Stimuli and apparatus

Experimental stimuli and apparatus were identical to those in Experiment 1, with the following exception. As the block cue, the words, "작은 손실" ("small loss" in Korean; 7.8° × 1.7°) or "큰 손실" ("large loss" in Korean; 5.8° × 1.7°) were presented to inform participants of the amount of punishment for each incorrect or slow response in a given block.

Procedure

The procedure was identical to that used in Experiment 1 with the following exceptions. At the end of each block in the main session, punishment feedback was presented for 1000 ms, displaying the amount of incentive lost during the block and the total amount of monetary incentive remaining at that moment (Fig. 1).

Results

Using the same exclusion criteria as in Experiment 1, approximately 0.21% of the total trials were excluded from the analyses. For each participant, the mean correct RT and PE were calculated as a function of Punishment (small, large), Previous Congruency (c, i) and Current Congruency (C, I). Repeated-measures ANOVAs were conducted on the mean RT and PE data. Descriptive statistics of behavioral data are summarized in Table 2. All data can be found on the Open Science Framework (OSF) at https://osf.io/yn94h.

Table 2 Descriptive statistics of behavioral data in Experiment 2

	Small punishment		Large punishment	
	c	i	c	i
RT				
C	464 (± 18.3)	469 (± 19.7)	443 (± 17.9)	446 (± 17.8)
I	492 (± 19.9)	475 (± 20.4)	480 (± 18.4)	459 (± 17.4)
Congruency effect	28	6	37	13
PE				
C	11.34 (± 3.34)	10.08 (± 2.75)	7.94 (± 2.24)	6.90 (± 1.69)
I	14.14 (± 3.21)	9.65 (± 2.62)	11.27 (± 2.38)	8.73 (± 2.91)
Congruency effect	2.79	− 0.43	3.34	1.83

Mean-centered 95% confidence intervals are in brackets. *C* congruent in current trial, *I* incongruent in current trial, *c* congruent in previous trial, *i* incongruent in previous trial

Punishment avoidance rates

Punishment avoidance rates were calculated for each participant by dividing the number of successful trials with correct and fast responses by the total number of trials as a function of Punishment, Previous Congruency, and Current Congruency. Participants avoided punishment on 82.16% of small punishment trials and 86.39% of large punishment trials, $F(1, 31) = 18.84$, $p < 0.001$, $MSe = 67.06$, $\eta_p^2 = 0.38$. Similar to Experiment 1, the punishment avoidance rate was higher on congruent (87.55%) than incongruent trials (82.81%), $F(1, 31) = 19.79$, $p < 0.001$, $MSe = 72.53$, $\eta_p^2 = 0.39$. Additionally, it was also higher on trials following incongruent trials (86.18%) than following congruent trials (84.18%), $F(1, 31) = 4.71$, $p = 0.038$, $MSe = 54.49$, $\eta_p^2 = 0.13$. Importantly, however, the interaction between Previous Congruency and Current Congruency was not significant, $F(1, 31) = 1.51$, $p = 0.229$, $MSe = 123.84$. Also, it did not interact with Punishment, $F(1, 31) = 0.90$, $p = 0.349$, $MSe = 38.03$. These results provide no evidence that the difficulties in avoiding punishment were different across trial types and punishment size. No other main or interaction effect was observed, $Fs(1, 31) < 1.19$, $ps > 0.284$ (Fig. 2).

RT

The main effect of Current Congruency was significant, $F(1, 31) = 45.66$, $p < 0.001$, $MSe = 633$, $\eta_p^2 = 0.60$, indicating a significant CE ($Ms = 455$ and 476 ms on congruent and incongruent trials, respectively). RT was also modulated by Previous Congruency, $F(1, 31) = 27.44$, $p < 0.001$, $MSe = 140$, $\eta_p^2 = 0.47$. Responses were faster after incongruent trials ($M = 462$ ms) than after congruent trials ($M = 470$ ms). Current Congruency interacted with Previous Congruency, $F(1, 31) = 40.96$, $p < 0.001$, $MSe = 198$, $\eta_p^2 = 0.57$, indicating a CSE. The CE was smaller after incongruent trials (10 ms), $t(31) = 2.73$, $p = 0.010$, than after congruent trials (32 ms), $t(31) = 9.18$, $p < 0.001$.

Punishment showed a significant main effect, $F(1, 31) = 60.35$, $p < 0.001$, $MSe = 347$, $\eta_p^2 = 0.66$. Mean RT was shorter in the large punishment blocks ($M = 457$ ms) than the small punishment blocks ($M = 475$ ms), showing that the motivation to avoid punishment facilitated response speed. Punishment did not interact with Previous Congruency, $F(1, 31) = 0.36$, $p = 0.554$, $MSe = 232$. However, the interaction of Punishment and Current Congruency was significant, $F(1, 31) = 4.16$, $p = 0.050$, $MSe = 238$, $\eta_p^2 = 0.12$). The magnitude of the CE was larger in large punishment blocks (25 ms), $t(31) = 8.39$, $p < 0.001$, than small punishment blocks (18 ms), $t(31) = 4.06$, $p < 0.001$. Importantly, a three-way interaction of Previous Congruency, Current Congruency, and Punishment was not observed, $F(1, 31) < 0.01$, $p = 0.953$, $MSe = 255$. The magnitude of the CE was reduced after incongruent trials compared to congruent trials, regardless of the punishment size (22 ms in small punishment and 24 ms in large punishment).

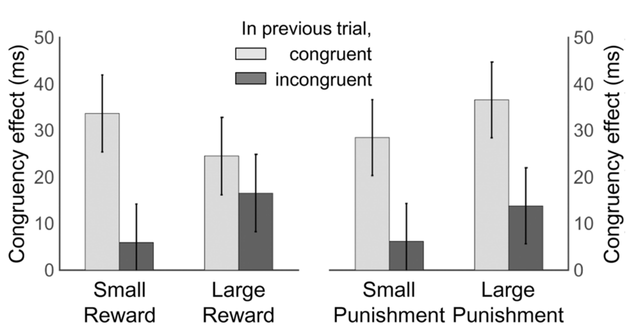

Fig. 2 The magnitudes of the CE for each experimental condition in Experiments 1 and 2. The CE was defined as mean RT difference between incongruent and congruent conditions in current trials. Error bars denote 95% confidence interval without individual variability (Loftus and Masson 1994)

PE

Consistent with the RT data, a significant main effect was obtained in Current Congruency, $F(1, 31) = 6.44$, $p = 0.016$, $MSe = 35.24$, $\eta_p^2 = 0.17$, showing a CE (9.06% in congruent and 10.95% in incongruent trials). The main effect of Previous Congruency was also significant, $F(1, 31) = 11.76$, $p = 0.002$, $MSe = 29.63$, $\eta_p^2 = 0.28$. Participants committed less errors after incongruent trials (8.84%) than after congruent trials (11.17%). However, the interaction between Previous Congruency and Current Congruency did not reach significance, $F(1, 31) = 1.57$, $p = 0.220$, $MSe = 56.92$, $\eta_p^2 = 0.05$.

The main effect of Punishment was significant, $F(1, 31) = 6.72$, $p = 0.014$, $MSe = 64.01$, $\eta_p^2 = 0.18$. Participants committed less errors in large punishment blocks (8.71%) than small punishment blocks (11.30%), indicating that the anticipation of large punishment motivated participants to respond more accurately. However, Punishment did not interact with either Previous Congruency, $F(1, 31) = 0.65$, $p = 0.428$, $MSe = 29.13$, $\eta_p^2 = 0.02$ or Current Congruency, $F(1, 31) = 1.10$, $p = 0.302$, $MSe = 28.39$, $\eta_p^2 = 0.03$. The three-way interaction of Reward, Previous Congruency, and Current Congruency was not significant, $F(1, 31) = 0.30$, $p = 0.586$, $MSe = 38.85$, $\eta_p^2 = 0.01$.

Discussion

Even though response speed and accuracy were enhanced when participants were motivated to avoid monetary punishment, such as when they were motivated to earn monetary incentives in Experiment 1, the CSE magnitude was almost identical in the small and large punishment blocks (22 ms and 24 ms, respectively), suggesting that the CSE was not modulated by aversive motivation. Some might argue that the modulation of the CSE by punishment was not observed because punishment was not effective enough. In the present experiment, punishment was a deduction of bonus money that was provided from an experimenter. Thus, it is possible that participants were not as concerned about losing bonus money as much as earning it. However, faster and fewer erroneous responses in the large compared to small punishment blocks indicated that the experimental manipulation of punishment in the present study was effective enough to motivate participants to avoid the punishment.

Interestingly, the magnitude of the CE increased with punishment size. Considering that the activation of task-irrelevant information decays over time (e.g., Hommel 1993; Lu and Proctor 1995 for review) and that the faster responses in large punishment were observed in the present experiment, the activation of task-irrelevant information could be relatively less decayed in large punishment blocks, resulting in a greater CE. However, in Experiment 1, it was not evident that the CE was modulated by the size of reward even though the mean RT decreased in large reward blocks. Thus, it is inconclusive if the greater CE was attributed to the faster responses in large punishment blocks. Alternatively, an aversive emotion by punishment might have impaired the cognitive ability to inhibit the impact of task-irrelevant information. It has been suggested that the anticipation of an aversive outcome provokes anxiety and/or stress, leading to behaviors avoiding from aversive outcomes (Lovibond et al. 2008; Seligman and Johnston 1973). In the present experiment, participants were at risk of receiving punishment even though it was escapable by rapidly making a correct response. Thus, they would try to respond both rapidly and correctly under the anxiety of potential punishment. Given the general consensus that anxiety interferes with cognitive processes (e.g. Eysenck et al. 2007), it is plausible to reason that anxiety during punishment anticipation resulted in a greater CE in the large punishment blocks than the small punishment blocks.

General discussion

In the present study, we investigated how appetitive motivation to earn monetary incentives or aversive motivation to not lose monetary incentives would modulate cognitive control in two separate experiments. Participants in both experiments were encouraged to maximize monetary incentives while performing Simon tasks. In both experiments, participants responded faster and more accurately when the amount of monetary incentive was large compared to when it was small, regardless of whether they were motivated to earn or to not lose the incentives. However, the impact of motivation brought out a sharp contrast in cognitive processes depending on the motivation type. Appetitive motivation debilitated cognitive control reducing the subsequent conflict. However, it was not evident that aversive motivation modulated the magnitude of the CSE.

The decrease of the CSE (i.e. deterioration of cognitive control) in the large reward blocks compared to the small reward blocks in Experiment 1 suggests that cognitive task performance can be impaired by motivation. It might be counterintuitive because previous studies have shown that cognitive processes are enhanced by appetitive motivation (Krebs et al. 2010; Padmala and Pessoa 2011; Savine et al. 2010). In the studies investigating the interaction between motivation and cognition, participants were typically informed about whether successful performance would be rewarded or not at the beginning of each trial. Based on advance knowledge about reward, participants could motivate themselves to perform the task more efficiently to increase the chance to obtain the reward. Thus, when a reward is anticipated, participants will prepare themselves for the upcoming target proactively, resulting in enhanced cognitive performance (Braver 2012). However, the recruitment of proactive control is a costly strategy because it is more effortful and sacrifices the involvement of reactive control (Westbrook and Braver 2016) and cognitive flexibility (Dreisbach and Fröber 2018). Even though reward makes cognitive efforts worthy to take, the reduced involvement of reactive control may result in impaired task performance in a situation where reactive control is crucial for performing tasks.

In a conflict task, interference of task-irrelevant information on a given trial triggers cognitive control reactively, which reduces interference on the subsequent trial (Botvinick et al. 2001; Duthoo and Notebaert 2012). The proactive control prioritized by reward prospect reduces interference on a given trial, which was demonstrated in previous studies (Krebs et al. 2010; Padmala and Pessoa 2011). However, the predominant involvement of the proactive control mode leaves less room for reactive control to be involved in modulating cognitive processes on the subsequent trials even if the proactive and reactive control modes do not have a push–pull relationship. Consequently, the sequential adjustment of conflict (i.e. CSE), which is the benefits from reactive control, disappeared because of the costs promoting proactive control during reward anticipation.

However, it is not clear why the modulation of the CSE by punishment was not observed in Experiment 2. Initially, we hypothesized that the magnitude of the CSE would be increased in punishment blocks if avoidance of punishment has differential effects on cognitive control compared to reward pursuit, such as biasing the system toward reactive control (Braver 2012) or enlarging the aversive signal of conflict in the previous trial (Dreisbach and Fischer 2015).

However, the results of Experiment 2 did not support our prediction. The simplest possible explanation is that aversive motivation is independent of the cognitive control that is responsible for the CSE. However, it is worthy to consider the result showing an increase of the CE (incongruent vs. congruent trial) in the large punishment relative to the small punishment blocks. If the potential punishment induced aversive emotion interfering with cognitive processes in general (Davis and Whalen 2001; Eysenck et al. 2007; Lovibond et al. 2008; Seligman and Johnston 1973), the increase of the CSE by punishment might be attenuated. Supporting evidence can be found in some recent studies. For instance, Yang et al. (2019) observed that the magnitude of the CSE was greater in the trials of negative feedback with monetary losses compared to the trials with positive feedback without monetary gains while the modulation of the CE by the negative feedback was not obtained. Yang and Pourtois (2018) also found similar results even though statistical results of the interaction between feedback type and CE were not reported. Based on the conflict monitoring theory of the CSE (Botvinick et al. 2001), it is assumed that the degree of conflict adjustment (i.e., CSE) would increase with the amount of conflict (i.e., CE). Thus, it might be questioned if the CSE is independent of the size of the CE under the influence of punishment. However, empirical studies did not show consistency in the relationship between the sizes of the CE and the CSE (Weissman et al. 2014). Further, other studies investigating the interaction between emotion and the CSE demonstrated that emotion modulated the CSE independently to the CE (van Steenbergen et al. 2009, 2010; Yang et al. 2019). Taken together, the results of Experiment 2 suggest that punishment might perform a double-duty, inducing aversive emotion which can impair cognitive processes as well as enhancing the cognitive control reducing the impact of task-irrelevant information.

In the same vein, the decrease of the CSE by appetitive motivation in Experiment 1 can be attributed to a positive emotion induced by reward. For instance, van Steenbergen et al. (2009) showed that the magnitude of the CSE was reduced on the trials after receiving a non-response-contingent reward. However, Stürmer et al. (2011) reported that the magnitude of the CSE was not affected by non-response-contingent rewards (Experiment 1), but it increased with response-contingent reward (Experiment 2). These intermixed results in the reward effect on the CSE can be attributed to the response contingency (e.g., Fröber and Dreisbach 2014). However, in the present study, the magnitude of the CSE was decreased by rewards even though the rewards were contingent on task performance as in Stürmer et al.'s Experiment 2. We thought the critical difference of the present study from others (van Steenbergen et al. 2009; Stürmer et al. 2011) is the motivational states induced by reward. Berridge and Robinson (2003) suggested that reward is constructed of three components, learning, liking, and wanting. In the former, the impact of reward on task performance was assessed while participants were pursuing a reward (i.e., before receiving a reward). Thus, the psychological states during task performance would be close to "wanting". In the latter studies, the reward effect was assessed by analyzing the task performance after receiving a reward. The hedonic experience of receiving reward would induce a psychological state close to "liking". Of course, it is still possible that participants experienced a positive emotion because they could evaluate their performance without explicit feedback in the present study. Further, it is plausible that they experienced an emotion by the incentive feedback at the end of each block, and their emotional experience influenced the task performance in the following block. However, the differences in experimental manipulations require cautious inference of the emotional effect from reward and punishment even though some of the results in the present study could be reconciled with the notion of emotions induced by reward and punishment.

The main purpose of the present study was to investigate the CSE modulated by appetitive motivation during reward pursuit, on the one hand, and aversive motivation during punishment avoidance, on the other hand. In contrast to previous studies, the present study demonstrated that the appetitive and aversive motivations can impede cognitive processes related to conflict (Experiment 2) or the sequential adjustment of cognitive processes (Experiment 1). In both experiments, the ultimate goal of participants was to maximize the total amount of monetary incentive by making fast and correct responses. Thus, the best strategy to perform the task would have been to respond to target stimuli rapidly and accurately without considering the conflict between target and response locations. Given the capacity limits of processing resources, focusing on a specific process (e.g. responding fast and accurately) can result in an impairment of other processes. In the present study, the impaired processes resulted in the cognitive control adjusting the impact of conflict in Experiment 1, and the cognitive process of task-irrelevant information in Experiment 2. Supporting evidence has been found in studies using the stop-signal paradigm. In a typical stop-signal experiment, participants are instructed to perform a task following two task rules; respond to a target stimulus as fast and accurately as possible, and stop responding if a stop-signal is presented. Interestingly, in one study, reward was provided after successful stopping with the stop signal, but fast and correct responses to a target were not rewarded (Boehler et al. 2012). On the contrary, in another study, participants obtained reward by making fast and correct responses to targets, but successful stopping was not rewarded (Padmala and Pessoa 2010). The results of these two studies showed that inhibitory control over responding was enhanced when stopping was emphasized by reward, whereas it was debilitated when responding was emphasized by reward. Taken together, the present study suggests that motivation does not necessarily have a global impact on our behaviors, but its effects are beneficial selectively to what is directly related to the goal, be that reward pursuit or punishment avoidance.

Conclusion

Most studies investigating the interaction between motivation and cognition have stressed that motivation is beneficial for behavior, such as increasing response speed and enhancing cognitive processes. If motivation has a beneficial effect globally, performance in cognitive tasks would be improved in general, regardless of the motivational valence. However, the results in the present study suggest that motivations with different valences may exert asymmetric interference on cognitive processes. The asymmetric interference suggests that aversive motivation has a distinct impact on cognitive processes from appetitive motivation even though both appetitive and aversive motivations might impede the cognitive processes that are not directly relevant to the goal at hand.

Author contributions JMC designed the study and preformed data collection, analysis, and interpretation. JMC drafted the manuscript, and YSC provided critical revisions.

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Compliance with ethical standards

Conflict of interest Author Jong Moon Choi and Yang Seok Cho 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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