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Unconscious impulsivity control maintains the ability of behavioral inhibitory control in males: Evidence of reaction-time cost

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Abstract: The present study investigated how unconscious priming of impulsivity control helps improve the performance of behavioral inhibitory control (BIC) using a Go/No-go task and a two-choice oddball task. Participants were divided into three priming conditions: impulsivity-avoiding (IA), calmness-pursuit (CP), and control group. Accuracy (ACC) cost (frequent–infrequent) in both tasks and reaction-time (RT) cost (infrequent–frequent) in the two-choice oddball task were used to assess BIC ability before and after the unconscious priming. The ACC cost, either in the Go/No-go or in the two-choice oddball task, was enhanced posttest relative to pretest, as indicated by the main effect of time. This effect arose from significantly increased ACC cost during posttest relative to pretest in the control group but not the IA and CP groups. Although no interaction of time and group was found in ACC cost analysis in either task, the analysis of RT cost in the two-choice oddball task showed a significant interaction between group and time. Specifically, the IA group showed similar RT cost during posttest versus pretest, while the RT cost was significantly enhanced during posttest versus pretest in the CP and control groups. These results suggest that unconscious pursuit of an impulsivity-avoidance goal is more effective in preventing one's impulsive behavior pattern than that of a calmness pursuit. Moreover, RT cost in the two-choice oddball task is a more sensitive index than the traditional ACC cost in assessing one's BIC function.

Keywords: behavioral inhibitory control; Go/No-go task; impulsivity control; two-choice oddball task; unconscious goal pursuit
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Behavioral inhibitory control (BIC) refers to the ability to withhold impulsive behaviors in context-inappropriate occasions, which plays an important role in one's adaption to changing environments (Li, Huang, Constable, & Sinha, 2006b; Patterson et al., 2016; Yuan, He, Qinglin, Chen, & Li, 2008). Dysfunction of BIC, as an important form of impulsivity, has been deemed to be relevant to violent, aggressive, or suicidal behaviors (Plutchik & Van Praag, 1989, 1995). Prior studies have often used a Go/No-go task to measure one's BIC ability. In this task, participants are instructed to respond to frequently occurring Go stimuli as quickly as possible; therefore, a prepotent response tendency can be established. On the other hand, the individual needs to refrain from response commission when an infrequent No-go stimulus appears. As a result of inhibiting the prepotent impulsive response pattern, the accuracy of a correct stop may be decreased in comparison with the accuracy of a hit to the Go stimulus (Albert, Lópezmartín, & Carretié, 2010). This accuracy (ACC) cost is the behavioral index of BIC during the Go/No-go task (Yuan, Xu, Yang, & Li, 2017).

However, few studies to date have examined how to influence one's BIC ability. In particular, it is important to examine how to enhance the performance of BIC. In a relevant study, Ditye, Jacobson, Walsh, and Lavidor (2012) found that brain stimulation by transcranial direct current stimulation (tDCS) could improve the ability of response inhibition. An anodal group, who experienced 4 days of consecutive tDCS, performed a stop-signal task better than the control group on the third and the fourth day. This indicates that anodal group participants' BIC ability improved as a result of consecutive anodal tDCS, as shown by the shortened stop signal response time (Ditye et al., 2012). In another study, Motes et al. (2014) used an inference training procedure to examine how response inhibition varied with this training. The results showed that 1-month strategic reasoning training, which taught structured strategies to infer the essential gist from materials, significantly enhanced one's performance of response inhibition (increased correct rejection to No-go trials) in a Go/No-go task (Motes et al., 2014). Despite effective intervention effects, both approaches produced beneficial effects at the cost of long-term training, irrespective of brain stimulation or cognitive training. It has been indicated that long-term cognitive training is resource-costly, and its complex procedure may result in midterm dropout (Cuijpers, Van Straten, Andersson, & Van Oppen, 2008; Weissman, 2007). Thus, it is necessary to seek more efficient, less costly methods for cognitive intervention of response inhibition.

In line with this purpose, recent studies on unconscious goal pursuit have shown that an unconscious goal can be automatically attained in the presence of a goal-related cue, without an individual's conscious supervision (Aarts & Dijksterhuis, 2000; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Gollwitzer & Bargh, 2005). Once activated, unconscious goals can operate just like consciously selected goals. In prior studies, an unconscious goal has usually been set up by a semantic priming task, which activates the goal successfully by constructing the relation between the goal and semantically related words (Chartrand & Bargh, 1996; Mauss, Cook, & Gross, 2007). Using a sentence-unscrambling task, an early study by Chartrand and Bargh (1996) required participants to reorganize a scrambled sentence that included synonyms of either *impression formation* or *memorization.* This task was followed by a sentence-reading task and then an unpredictable free-recall task. The result revealed that the memorization group recalled significantly more reading sentences than did the impression formation group (Chartrand & Bargh, 1996). Recently, researchers have used the methods of unconscious goal pursuit to investigate unconscious emotion regulation. For instance, using a sentence-unscrambling task that includes critical words of emotional suppression, Mauss et al. (2007) found that unconscious priming of emotional control reduced one's anger experiences without maladaptive physiological consequences. Consistent with this finding, Williams, Bargh, Nocera, and Gray (2009) and Yuan, Ding, Liu, and Yang (2015), using a similar paradigm, observed that unconscious priming of a reappraisal goal downregulated heart rate reactivity as effectively as intentional reappraisal during anticipatory stress and frustration emotion, respectively.

According to Bargh's auto-motive model, if an individual consistently pursues a goal in a social situation, this goal will automatically form a connection with the appropriate situation representation in the brain (Gollwitzer & Bargh, 2005). The operation of unconscious goal pursuit is due to the automatic activation of goal representation by goal-related cues, and forms the connection between behaviors and results at the level of perception and behaviors (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Therefore, activating a behavior or its results can make people take actions. For example, Pulvermüller (2005) found that by seeing or reading information concerning a behavior or its results, people's tendencies to achieve goals could be improved. Language understanding makes language connected with subsequent behaviors, probably due to our automatic and quick link between sensory and motor information in the brain, which helps comprehension and learning processes (Pulvermüller, 2005). If the connection between goal representation and cues preexisting in the cognitive structure is activated, people will automatically select and execute goal behaviors (Custers & Aarts, 2007). Given this evidence, it is likely that unconscious priming of the goal of impulsivity control may also enhance one's BIC performance.

According to the theory of unconscious goals, if individuals were required to complete a task containing clues for the goal of impulsivity control before a BIC task, which is to form the goal of impulsivity control at the unconscious level, then these clues would connect with the representation of impulsivity control goal in the brains of the individuals. The unconscious goal can guide individuals to flexibly adapt their behaviors to the task requirements in order to achieve the goal. In BIC tasks, individuals need to inhibit the tendency of the dominant response, which is expressed as the ACC cost or reaction-time (RT) cost between the Go stimulus (standard stimulus) and No-go stimulus (deviant stimulus). Individuals who activate an impulsivity control goal will increase their focus on the task and reduce impulsivity, in order to gain better task performance. However, currently no study has directly investigated whether the method of unconscious goal pursuit can also be used to improve one's performance of BIC when the impulsivity control goal is unconsciously primed.

Thus, the present study investigated whether unconscious priming of the goal of impulsivity control may improve one's performance of BIC using the Go/No-go and two-choice oddball task. As stated above, the Go/No-go task is a classic paradigm to assess one's BIC ability, and impulsivity is manifested by ACC reduction during No-go relative to Go trials (ACC cost; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Yuan et al., 2017). However, a couple of studies indicate that the index of ACC cost in the Go/No-go task is insensitive to intra-individual BIC variations (Goldstein et al., 2007; Yu, Yuan, & Luo, 2009). Moreover, as participants are required to withhold response to No-go trials in the Go/No-go task, this paradigm provided no RT index of BIC. Alternatively, the two-choice oddball task, which requires different responses to both frequent standard and infrequent deviant stimuli, provides not only ACC cost but also an RT cost during deviant versus standard trials (i.e., RT delay for deviant vs. standard trials). This index has proven effective to detect individual differences in impulsivity or BIC that cannot be detected by ACC cost (Wang et al., 2011; Yuan et al., 2008, 2017; Zhao, Liu, Yi, Dai, & Bao, 2015). Based on this consideration, the current study used both paradigms to examine how unconscious priming of impulsivity control modulates BIC.

Unthinking action is one form of impulsivity, characterized by hyperactivity and a lack of thoughtfulness or concern for the environment. Since impulsive behavior is often defined as a lack of cognitive control over behavior, unthinking action is thought to be associated with weaker executive function (Romer, 2010). BIC tasks assess the ability to monitor conflicting cues to action and inhibit prepotent responses that are no longer adaptive, which is in nature a response-decision process. A variety of contexts are deemed to modulate reward and cognitive control processes. In particular, social contexts can have a powerful influence on one's decisions about risk and reward. This reward structure, provided by social cues, works by a way of approval and disapproval (Engelmann, Moore, Capra, & Berns, 2012). Therefore, it is expected to effectively reduce impulsivity by establishing the emotional connection of individuals to specific impulsive behavior patterns, that is, to establish the positive emotional connection to the goal with positive value or to establish the negative emotional connection to the negative results caused by impulsivity. This reasoning is supported in part by research, for example, that providing adolescents with expert advice on coping with risky behaviors increases their aversion to risky options. At the same time, it reduces the response strength of reward neural circuits (such as the ventromedial prefrontal cortex) to risk selection and enhances the response strength of cognitive control circuits (such as dlPFC) to safe selection. This suggests that providing additional information helps to improve individuals' cognitive control function and emotional regulation ability for reward, thus reducing impulsive decision-making behavior (Engelmann et al., 2012). This means, by means of semantic priming, that it is possible to enhance individuals' control of impulsive behavior patterns and thus reduce the generation of impulsive behavior.

Based on the reviewed studies of unconscious goal pursuit, we predicted that unconscious priming of impulsivity control could enhance or maintain one's performance of BIC. Impulsivity control was unconsciously primed using a sentence-unscrambling task. As mentioned above, we planned to establish positive emotional connections to goals with positive values and negative emotional connections to the consequence of impulsivity, to increase one's BIC performance through semantic priming. Two types of impulsivity control goals were primed: one was to semantically prime the impulsivity-avoidance goal by accessing adverse consequence of impulsivity; and the other was to prime the calmness-pursuit goal by accessing the benefits of calmness. Despite a similar goal to reduce impulsivity, the semantic representations of impulsivity-inhibitory concepts were different between these two methods. Specifically, impulsivity avoidance is suppressing impulsivity by emphasizing the negative consequences of impulsive behaviors, while calmness pursuit focuses more on the strength of calmness maintenance in the management of impulsive behaviors. It is undetermined whether the two unconscious methods of impulsivity control work similarly, or differently, in the improvement of one's impulsivity control. Therefore, we set impulsivity avoidance and calmness pursuit as two different tasks to prime the goal of impulsivity control. Through these two unconscious goals, participants were expected to establish the positive emotional connection to the goal with positive value or to establish the negative emotional connection to the consequence of impulsivity, which is supposed to facilitate subjects' focus on the goal of improving BIC by influencing the cognitive control system.

We manipulated these two priming conditions, as daily-life impulsivity control usually involves scenarios of both suppressing impulsive behavior directly and calming down cognitively. As the method of calming oneself down cognitively often occurs in emotionally provocative situations (e.g., anger), we further predicted that unconscious priming of impulsivity avoidance may generate an optimal intervention effect on BIC compared to that of calmness pursuit.

Method

Participants

Seventy-two male participants with an age range of 17–27 years (M = 20.26 ± 0.229 years; SD = 1.916 years) from Southwest University were paid to participate in the study. Software Gpower 3.1 was used to measure the adequacy of the sample size in three conditions. The results showed that in the conditions where effect size = 0.25, α err prob. = .05, and power > 0.95, a sample size of over 65 was needed. Therefore, the sample size of the present study met the requirements. All participants were right-handed and reported normal or corrected-to-normal vision. A previous study has shown that females may have advantages in BIC, which is indicated by faster detection and resolution of response conflicts than males (Yuan et al., 2008). Thus, only males were recruited in this study. All participants signed written informed consent and got paid for their participation. The present study was approved by the local ethics committee of Southwest University and the academic committee of the School of Psychology, Southwest University in China.

Before the experiment, participants were randomly assigned to one of three groups: the impulsivity-avoidance (IA) group, the calmness-pursuit (CP) group, or the control group. The final analysis consisted of 24 participants in each group. To ensure the effectiveness of the random assignment of participants, all participants were asked to complete measurements related to emotional states, and emotionally relevant personality traits. The between-group comparison in these measures showed that the three groups of participants were highly similar in the assessment of state and trait anxiety, depression, impulsivity, emotional stability, self-esteem, and emotion-regulation tendencies, including all $F(2, 69) < 1$, *ns* (see Figure 1).

In addition to the above assessments, the demographic questionnaire was also set up to verify whether there was a significant difference among the three groups in regards to alcohol drinking, smoking, and gambling. The results showed that eight participants smoked, 21 participants drank alcohol, and three participants gambled. The proportion of these participants was comparable in the three groups, verified by insignificant differences among three groups in smoking, $\chi^2(2) = 1.125$, $p = .570$; drinking, $\chi^2(2) = 1.613$, $p = .446$; and gambling, $\chi^2(2) = 2.087$, $p = .352$ in the chi-squared test.

Materials

The BIC task consisted of the Go/No-go task and the two-choice oddball task. The two tasks had the same structure. Both tasks included two types of stimuli, and the presentation ratio of the two types of stimuli was 80% versus 20%. Specifically, the Go stimulus and standard stimulus were frequently presented (at 80%), while the No-go and deviant stimuli were infrequent (at 20%). In Go or standard trials, a picture with printed capital W was presented, while in the No-go or deviant trials a picture with printed capital M was presented. The resolution of pictures was 126 × 126, and the size of pictures was 3.3 cm × 3.3 cm. The letters were located in the midpoint of their respective backgrounds (letters in black and background in white). The screen was in front of the participants and the straight-line distance between the participant and the screen was about 0.5 m. Therefore, the vertical and horizontal angles were both below 6°.

We adopted the sentence-unscrambling task (Bargh et al., 2001; Srull & Wyer, 1979) for unconscious priming of goal pursuit, in which participants were instructed to pick up four words from the five given words to construct a grammatical sentence. Sentence-unscrambling tasks with three different types of sentences were set for the three groups, respectively. Participants in the IA group were asked to unscramble sentences conveying bad consequences of impulsive behaviors (e.g., "Impulsivity makes people wrong"). Participants in the CP group were asked to unscramble sentences conveying the benefits of behaving calmly (e.g. "Calmness helps solve problems"; see Figure 2B). In these two groups above, 16 of the 21 sentences were designed for priming goal pursuit. The rest of the five sentences irrelative to goal pursuit were designed to avoid exposing the experiment purpose. Participants in the control group were instructed to accomplish the task

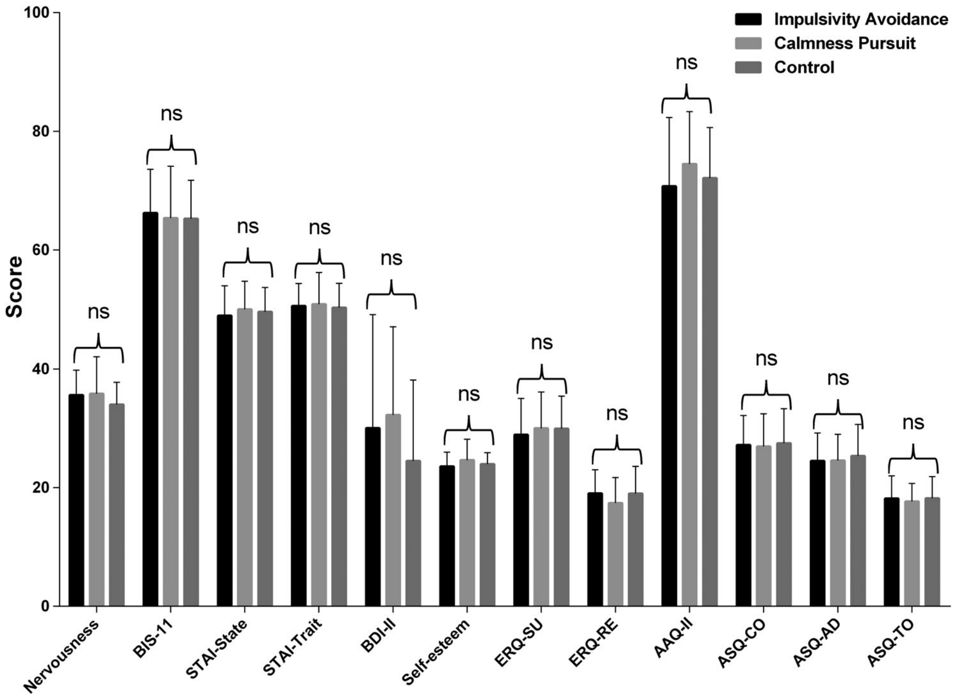

Figure 1. The scores of the three groups on the Big Five (NEO-FFI)–Neuroticism (Nervousness) (Yao & Liang, 2010), Barratt Impulsiveness Scale (BIS-11) (Zhou, Xiao, He, Li, & Liu, 2006), Spielberg State Anxiety Scale (STAI-State), Spielberg Trait Anxiety Scale (STAI-Trait) (Li & Qian, 1995), Beck Depression Inventory-II (BDI-II) (Wang et al., 2011), Rosenberg Self-Esteem Scales (Self-Esteem) (Ji & Yu, 1993), Emotion Regulation Questionnaire – Suppression (ERQ-SU) (Wang, Liu, Li, & Du, 2007), Emotion Regulation Questionnaire – Reappraisal (ERQ-RE) (Wang et al., 2007), Acceptance and Action Questionnaire - II (AAQ-II), (Cao, Ji, & Zhu, 2013), Affective Style Questionnaire – Concealing (ASQ-CO) (Liu, Zhou, & Ping, 2011), Affective Style Questionnaire – Adjusting (ASQ-AD) (Liu, Zhou, & Ping, 2011), and Affective Style Questionnaire – Tolerating (ASQ-TO) (Liu, Zhou, & Ping, 2011). Error bars represent the standard errors of the mean values. *ns* = not significant.

including 21 sentences unrelated to goal pursuit (e.g., “The moon rose up”).

BIC task

The BIC task consisted of the Go/No-go task and the two-choice oddball task and they had the same two-block structure with 150 trials per block. There were 120 Go trials and 30 No-go trials for each block in Go/No-go task, and 120 standard and 30 deviant trials for each block in the two-choice oddball task. The ratio of two types of stimuli was 80% versus 20% in both two tasks (see Figure 2C). A 30-s break was set up between two blocks. In the formal experiment, a red fixation point, whose duration varied randomly between 500 ms and 1500 ms, was presented on the midpoint of the computer screen at first in each trial. Then, two types of stimuli appeared at random for 1000 ms. In the Go/No-go task, participants were instructed to press the “1” key with their right index fingers to respond to Go trials quickly and correctly and not to press any key in the No-go trials. However, in the two-choice oddball task, participants were instructed to press the “1” key with their right index fingers to respond to standard trials, and to press the “2” key with their right middle fingers to respond to deviant trials. The presentation of stimuli was terminated by a key pressing or when the stimulus appeared for 1000 ms. For this reason, participants were informed that they must respond within 1000 ms. At the end of each task, accuracy rates for the two types of stimuli were presented on the screen as feedback.

A practice including 15 trials was used before each task in order to familiarize participants with the experiment procedure. No-go trials and deviant trials in practice appeared at the same rate as in the formal experiment, and accuracy rates were also presented on the screen as feedback. To ensure every participant fully understood the requirement of the experiment, only the participants whose accuracy rate reached 100% in the practice would be allowed to enter into the formal experiment.

Unconscious goal-priming task

As an unconscious goal-priming task, the sentence-unscrambling task (Bargh et al., 2001; Srull & Wyer, 1979) was used to activate either the goal of impulsivity avoidance or calmness pursuit. All participants were asked to accomplish 21 sentences, and feedback was provided after each sentence was unscrambled. A practice with two trials of sentence makeup was used before the formal task. To ensure participants understood the task requirement, only the participants who had accomplished the practice correctly were permitted to enter into the formal task.

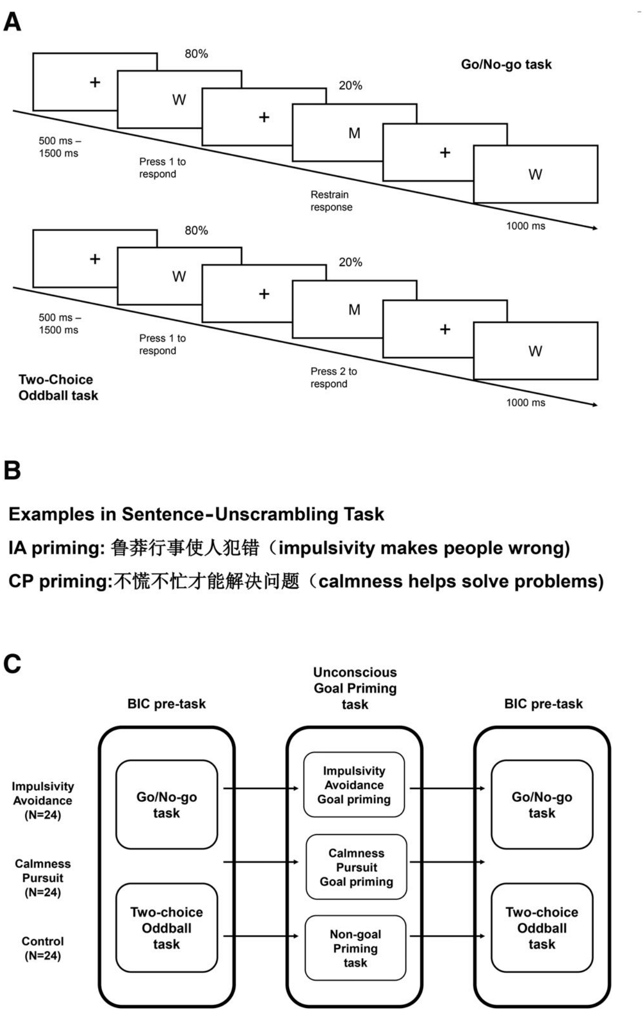

Figure 2. (A) The organization illustration for the study design. (B) Examples for impulsivity-avoidance (IA) priming task and calmness-pursuit (CP) priming task. (C) Illustration of behavioral procedure of Go/No-go task and the two-choice oddball task.

Procedure

The formal experiment was composed of three sessions. First of all, all participants were asked to accomplish the BIC task consisting of the Go/No-go task and the two-choice oddball task (pretest). Second, the three groups accomplished three different unconscious priming tasks, respectively. Specifically, the participants in the IA group were instructed to accomplish the task that primed the semantic information of impulsivity avoidance; the participants in the CP group were instructed to accomplish the task that primed semantic information of calmness pursuit; and the participants in the control group were instructed to accomplish the task unrelated to goal pursuit. Third, all participants were asked to perform the BIC task for the second time (posttest), in order to assess the ability of BIC after unconscious priming of impulsivity control. The order of the Go/No-go task and the two-choice oddball task was counterbalanced among the participants. A 1-min break was used between every two sessions to control fatigue (see Figure 2A). At the end of the whole experiment, all the participants were asked to guess how the words in the scrambled-sentence task were related to the subsequent task. No participant was aware or suspicious that the words were related to the subsequent BIC task.

Data analysis

In the Go/No-go task, *ACC cost* was defined as the reduction of accuracy rates from Go to No-go conditions (Go-Nogo), which was used to reflect how one's performance of BIC varied with unconscious priming. In the two-choice oddball task, both RT and ACC for standard and deviant stimuli were collected. The *ACC cost* was defined as the accuracy reduction from standard to deviant trials, while the *RT cost* was defined by the reaction time delay from standard to deviant trials (deviant – standard). Only correctly reacting trials were counted when calculating RT.

A 2×3 mixed-design analysis of variance (ANOVA) was conducted for ACC cost and RT cost with time (pretest and posttest) as the within-subject factor and group as the between-subject factor (IA, CP, and control). In manipulation check, a repeated-measure ANOVA was conducted on ACC and RTs with stimuli types as a within-subject factor (Go vs. No-go, or standard vs. deviant) and group as the between-subject factor (IA, CP, and control). The behavioral data were analyzed with SPSS Version 21 general linear model software. The Greenhouse–Geisser correction was applied to the degrees of freedom of the F ratio and the p values in all these analyses. All simple effect analyses were corrected using a Bonferroni correction. Results with p values less than .05 are considered to reflect significant differences in comparison. Effect size as a value reflecting the size of difference among the population means was calculated in all analyses.

Results

Manipulation check: Impulsive behavior elicitation

Go/No-go task

In the pretest data without priming of impulse control, the repeated-measures ANOVA (stimuli types as a repeated factor and group as a between-subjects factor) on ACC of the

Go/No-go task revealed a significant main effect of stimuli types (Go vs. No-go), $F(1, 69) = 51.097$, $p < .001$, $\eta^2 = .425$, with No-go trials linked with reduced ACC compared to Go trials. No other effects were found (see Figure 3).

Two-choice oddball task

Similarly, the repeated-measures ANOVA on the pretest ACC of the two-choice oddball task revealed a significant main effect of stimuli type (standard vs. deviant), $F(1, 69) = 66.183$, $p < .001$, $\eta^2 = .490$, with deviant trials eliciting lower ACC compared to standard trials, irrespective of group assignment. Moreover, the repeated-measures ANOVA on RTs revealed a significant main effect of stimuli type, $F(1, 69) = 409.055$, $p < .001$, $\eta^2 = .856$. All three groups showed longer RTs for deviant stimuli than for standard stimuli. No other effects were found (see Figure 3).

These data indicated that all participants responded more slowly and less accurately to infrequent stimulus than to frequent stimulus, irrespective of task. This suggests that both BIC tasks successfully elicited one's impulsive behavioral pattern, irrespective of group. In addition, both tasks demonstrated no stimulus-by-group interaction—Go/No-go: $F(2, 69) = 0.837$, $p = .437$, $\eta^2 = .024$; ACC in the two-choice oddball: $F(2, 69) = 0.227$, $p = .797$, $\eta^2 = .007$; RT in the two-choice oddball: $F(2, 69) = 0.051$, $p = .950$, $\eta^2 = .001$—suggesting effective randomization of subjects into different groups.

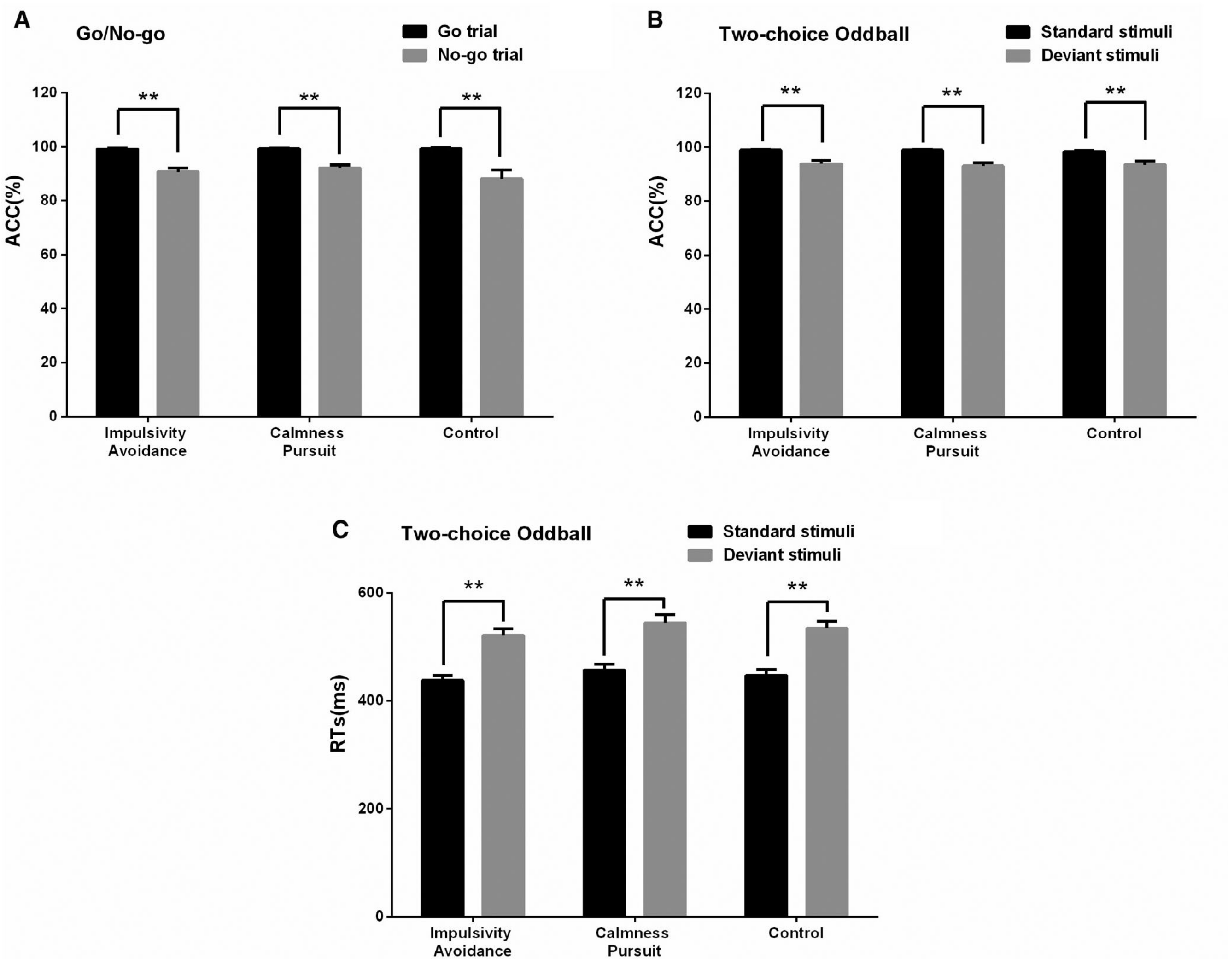

Figure 3. Manipulation check for experimental stimuli in accuracy (ACC) cost of (A) the Go/No-go task and (B) the two-choice oddball task, as well as (C) the reaction-time (RT) costs of the two-choice oddball task. Error bars denote the standard errors of the mean. $^{**}p < .01$.

Unconscious priming effect

Go/No-go task

ACC cost

A repeated-measures ANOVA on ACC cost, with time (pretest, posttest) as a within-subject factor and group (IA, CP, control) as a between-subject factor, revealed a significant main effect of time, with posttest exhibiting a larger ACC cost compared to pretest, $F(1, 69) = 4.069$, $p = .048$, $\eta^2 = .056$. This effect resulted from increased ACC cost during posttest versus pretest in the control group ($p = .022$) but not in the CP ($p = .320$) or IA ($p = .969$) groups. The main effects of group ($p = .237$) and time-by-group interaction ($p = .195$) were insignificant (see Figure 4).

Two-choice oddball task

ACC cost

A repeated-measures ANOVA on ACC cost, with time (pretest, posttest) as a within-subject factor and group (IA, CP, control) as a between-subject factor, revealed a significant main effect of time, with posttest exhibiting a larger ACC cost compared to pretest, $F(1, 69) = 7.813$, $p = .007$, $\eta^2 = .102$. Again, this effect was accounted for by increased ACC cost during posttest versus pretest in the control group ($t = -2.075$, $p = .049$) but not in the CP group, $t(23) = -1.350$, $p = .190$, or in the IA group, $t(23) = -1.575$, $p = .129$. The main effect of group ($p = .570$) and the time-by-group interaction ($p = .162$) were insignificant (see Figure 4).

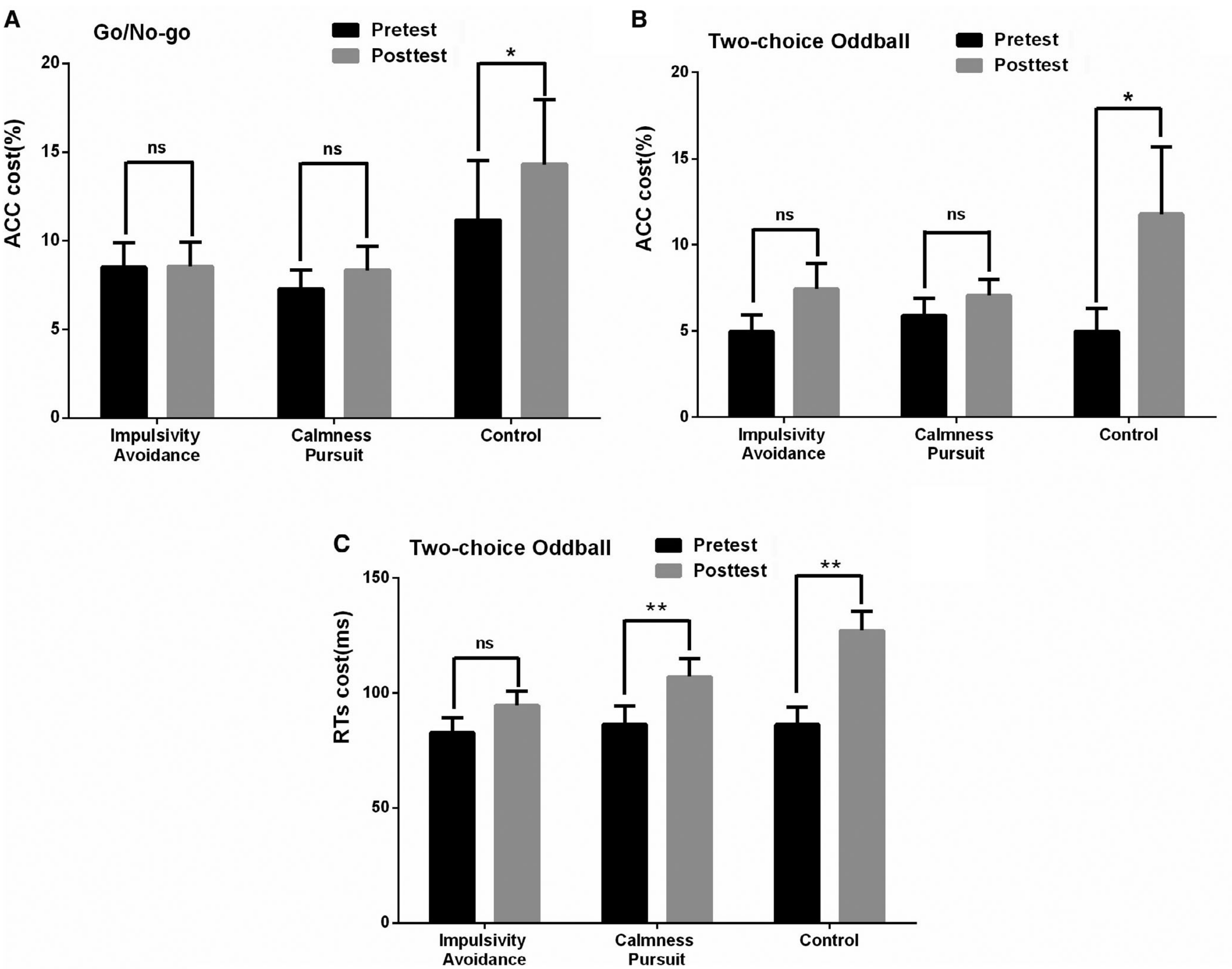

Figure 4. (A) Accuracy (ACC) cost of Go/No-go task and the (B) two-choice oddball task as well as (C) the reaction-time (RT) costs of the two-choice oddball task, varying as a function of test time point in each group. Error bars represent the standard errors of the mean values. *ns* = not significant. $^*p < 0.05$; $^{**}p < 0.01$.

Table 1
Mean RT Costs (M ± SD) for Pretest and Posttest in Each Group and Their Statistics

	IA	CP	Control	*F* value	*p* value	η_p^2
Pretest	82.739 ± 31.626	86.313 ± 39.407	86.264 ± 36.725	$F(2, 69) = 0.077$	.926	.002
Posttest	94.592 ± 30.310	107.057 ± 39.135	127.212 ± 39.998	$F(2, 69) = 4.817$	.011	.123
t value	$t(23) = -1.794$	$t(23) = -5.011$	$t(23) = -4.890$			
p value	.086	<.001	<.001			
Cohen's *d*	0.383	0.528	1.066			

Note. IA = impulsivity-avoidance group; CP = calmness-pursuit group; C = control group.

RT cost

The averaged RT costs of each group for pretest and posttest are shown in Table 1. A repeated-measures ANOVA on RT costs showed a significant main effect of time, $F(1, 69) = 43.311$, $p < .001$, $\eta^2 = .374$, and a significant time-by-group interaction, $F(2, 69) = 5.094$, $p = .009$, $\eta^2 = .13$. The simple effect analyses showed significantly increased RT cost during posttest versus pretest in the CP group, $t(23) = -5.011$, $p < .001$, Cohen's $d = 0.5282$, and control group, $t(23) = -4.890$, $p < .001$, Cohen's $d = 1.0665$, but not in the IA group, $t(23) = -1.794$, $p = .086$, Cohen's $d = 0.3826$. On the other hand, posttest-related RT cost was significantly reduced for the IA group versus the control group ($p = .003$) while the posttest-related RT cost was not significantly different between the CP and control groups ($p = .062$; see Figure 4). The main effect of group was insignificant, $F(2, 69) = 1.850$, $p = .165$.

Discussion

In the current study, we used the Go/No-go task and the two-choice oddball task to investigate how unconscious priming of impulsivity control modulates one's performance of BIC in adult males, a population reported to be less capable of BIC than their female counterparts (Li, Huang, Constable, & Sinha, 2006a; Yuan et al., 2008). First, the manipulation check showed decreased ACC during No-go (deviant) compared to Go (standard) trials, irrespective of which task was used and which group was involved. Also, the two-choice oddball task showed delayed RTs for deviant relative to standard trials across groups. These data suggest that the Go/No-go and the two-choice oddball tasks both elicited significant effects of BIC, as manifested by the significant ACC cost. This is in line with prior studies with the Go/No-go task that reported decreased accuracy for No-go compared to Go trials (Albert et al., 2010; Nieuwenhuis et al., 2003). However, the latter task provided a supplementary BIC-related RT index, consistent with prior studies (Yuan et al., 2017; Zhao et al., 2015).

The analysis of the intervention effects in ACC cost showed a similar main effect of time in both tasks, with the ACC cost enhanced during posttest compared to pretest. However, this main effect arose from the enhanced ACC cost during posttest relative to pretest in the control but not the other two groups. This suggests that unconscious priming of impulsivity control, to some extent, is effective in preventing one's exacerbation of impulsive behavior inhibition over time, consistent with prior studies of unconscious goal pursuit in other domains, such as emotion regulation or cognitive enhancement (Chartrand & Bargh, 1996; Mauss et al., 2007; Williams et al., 2009). However, we need to take caution with this argument, as we did not observe significant time-by-group interaction effect in ACC cost. In other words, statistically speaking, it is difficult to argue that the intervention effect on ACC cost is effective. It shows only a possible trend, not solid evidence. In this regard, we should study whether the intervention program is effective at the neurological level, through electrophysiological methods in the future. The lack of a significant interaction effect in ACC cost was, at least in part, due to the fact that the ACC cost during No-go (deviant) compared to Go (standard) trials was insensitive to the interindividual or intraindividual differences in behavioral inhibitory functions, as reported by prior studies using Go/No-go (Bekker, Kenemans, & Verbaten, 2005; Yu et al., 2009) and the two-choice oddball task (Wang et al., 2011; Yuan et al., 2008).

However, partially consistent with the assumptions, results indicated that unconscious priming of the IA task effectively prevented the decline in BIC ability while the performance of BIC significantly declined in the CP and control groups, as indicated by the significant time-by-group interaction effect on the RT cost in the two-choice oddball task. Participants in both the CP group and the control group showed higher RT cost in posttest compared to the pretest. This indicates a decline in one's BIC ability in continued performance of impulsive response inhibition in the control and CP group. In Muraven's strength model, self-control is considered as a kind of limited resource and as subject to temporary depletion. If people have used too much of their control resources in the previous task, they may not perform well in other tasks that might require self-regulation (Muraven, Tice, & Baumeister, 1998). This ability to interrupt or modulate one's own responses has many behavioral patterns. As a representative form of self-control, behavioral inhibition also has a limit as a resource. In a pretest, a participant might temporarily run out of cognitive resources. Therefore, the performance might decline in the posttest. However, this declining effect probably as a result of fatigue was not observed in the IA group. This, on the one hand, suggests that unconscious priming of impulsivity avoidance achieves a better protective effect than that of calmness pursuit on one's BIC function. In life settings, the strategies of calming oneself down often works in the context of intense emotion induction, such as anger or fear elicitation (Delgado, Nearing, Ledoux & Phelps, 2008; Mauss et al., 2007). Closer to the current study, Chen et al. (2017) observed an unconscious emotion-regulation effect for social learning of fear using unconscious priming of calmness pursuit (Chen et al., 2017). However, the current study did not subject participants to an emotion-evocative procedure and their impulsive behavioral patterns were induced by repeated and habitual response to the frequent stimulus irrelevant to emotion. This may account for why IA priming produced a better protective effect on behavioral inhibitory function than CP priming as measured by the RT cost. Although both impulsivity avoidance and calmness pursuit hint at the goal of impulsivity control, they include different types of cues for connecting to the goal. In order to prevent the interaction between these two different types of clues, we set impulsivity avoidance and calmness pursuit as two different tasks. From the experimental results, priming for the impulsivity avoidance goal was linked with better performance of BIC than priming for the calmness pursuit goal. This suggests that these two methods may work in different situations of impulsivity control.

On the other hand, we observed no significant time-by-group interaction in ACC cost across the two tasks, whereas a highly significant time-by-group interaction was observed in the RT cost index during the two-choice oddball task. This suggests that the RT cost index in the two-choice oddball task is more sensitive than the traditional ACC cost in detecting individual alterations of BIC function. This was supported by a couple of previous studies, which reported sex-related or addiction-related differences in BIC in RT cost but not in ACC index (Yuan et al., 2008; Zhao et al., 2015). Also, there is evidence showing that the RT cost, which is unique to the two-choice oddball task, can predict how behavioral inhibitory function varies with emotion elicitation while this predicting role was not found for the ACC cost (Wang et al., 2011; Yuan et al., 2012). These evidences offer an implication that the RT cost provided by the two-choice oddball task is a more sensitive measure to detect inter-individual or intraindividual differences in humans' BIC function.

Several limitations need to be acknowledged. One limitation was that only males were included in the analysis. Although the unconscious goal-priming task has been proven as helpful in improving males' BIC ability, whether it has the same effect on females is still unknown. Besides, both male and female participants were included in the unconscious goal studies (e.g., Bargh, Chen, & Burrows, 1996; Bargh et al., 2001), but it is still unclear whether it has different influence across sexes. Future studies could examine gender differences in the influence of unconscious goal priming on BIC. Another limitation was that the current study did not collect electrophysiological data to support out hypothesis. In further studies, we plan to study the role of unconscious goals in the regulation of BIC through electrophysiological techniques to obtain more reliable data support.

As a way of implicit priming and low consuming of cognitive resources, unconscious goal pursuit may be of practical implication in helping people with impulsive control defects. Research on early interventions indicates that the training regarding executive functioning and self-regulation can reduce impulsivity, otherwise the impulsivity might lead to maladaptive outcomes in adolescence, such as impaired school performance (Romer, 2010). This suggests that early intervention in children is crucial to prevent behavioral inhibition and control deficits when they enter into adolescence. For example, children with attention deficit hyperactivity disorder may find it difficult to perform well in BIC tasks, due to their impulsivity. In a previous study, children with attention deficit hyperactivity disorder and oppositional deviant disorder showed worse performance in the stop signal task (Scheres, Oosterlaan, & Sergeant, 2010). The unconscious goal of impulsivity control can be used as a means to reduce impulsivity by establishing a positive emotional connection to a goal with positive value or building a negative emotional connection to the consequence of impulsivity. In other words, unconscious goal priming tasks enable them to focus more on BIC tasks by establishing goal representations of impulsivity control in their brains. This method requires little conscious effort and time cost and is thus worthy of generalization.

Conclusion

The present study shows that unconscious priming of impulsivity control, in particular by priming impulsivity avoidance directly, may help to maintain one's ability of behavioral inhibitory control from being disturbed by other factors (e.g., fatigue or self-depletion). In addition, the RT cost index, which is unique to the two-choice oddball task, is a more sensitive marker to detect changes in one's behavioral inhibitory function compared to the traditional accuracy index in the Go/No-go task.

Disclosure of conflict of interest

All authors report no biomedical financial interests or potential conflicts of interest.

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References

Aarts, H., & Dijksterhuis, A. (2000). Habits as knowledge structures: Automaticity in goal-directed behavior. *Journal of Personality & Social Psychology*, *78*(1), 53–63. http://doi.org/10.1037/0022-3514.78.1.53

Albert, J., Lópezmartín, S., & Carretié, L. (2010). Emotional context modulates response inhibition: Neural and behavioral data. *NeuroImage*, *49*(1), 914–921. http://doi.org/10.1016/j.neuroimage.2009.08.045

Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype-activation on action. *Journal of Personality and Social Psychology*, *71*(2), 230–244. http://doi.org/10.1037/0022-3514.71.2.230

Bargh, J. A., Gollwitzer, P. M., Lee-Chai, A., Barndollar, K., & Trötschel, R. (2001). The automated will: Nonconscious activation and pursuit of behavioral goals. *Journal of Personality & Social Psychology*, *81*(6), 1014–1027. http://doi.org/10.1037/0022-3514.81.6.1014

Bekker, E. M., Kenemans, J. L., & Verbaten, M. N. (2005). Source analysis of the n2 in a cued go/nogo task. *Brain Research Cognitive Brain Research*, *22*(2), 221–231. http://doi.org/10.1016/j.cogbrainres.2004.08.011

Cao, J., Ji, Y., & Zhu, Z. (2013). Reliability and validity of the Chinese version of the Acceptance and Action Questionnaire-Second Edition (AAQ-II) in college students. *Chinese Mental Health Journal*, *27*(11), 873-877. http://doi.org/10.3969/j.issn.1000-6729.2013.11.014

Chartrand, T. L., & Bargh, J. A. (1996). Automatic activation of impression formation and memorization goals: Nonconscious goal priming reproduces effects of explicit task instructions. *Journal of Personality & Social Psychology*, *71*(3), 464–478. http://doi.org/10.1037/0022-3514.71.3.464

Chen, S., Deng, Z., Xu, Y., Long, Q., Yang, J., & Yuan, J. (2017). Individual differences in spontaneous expressive suppression predict amygdala responses to fearful stimuli: The role of suppression priming. *Frontiers in Psychology*, *8*(S497), 1042–1053. http://doi.org/10.1080/02699931.2014.965663

Cuijpers, P., Van Straten, A., Andersson, G., & Van Oppen, P. (2008). Psychotherapy for depression in adults: A meta-analysis of comparative outcome studies. *Journal of Consulting and Clinical Psychology*, *76*(6), 909–922. http://doi.org/10.1037/a0013075

Custers, R., & Aarts, H. (2007). Goal-discrepant situations prime goal-directed actions if goals are temporarily or chronically accessible. *Personality and Social Psychology Bulletin*, *33*(5), 623–633. http://doi.org/10.1177/0146167206297404

Delgado, M. R., Nearing, K. I., LeDoux, J. E., & Phelps, E. A. (2008). Neural circuitry underlying the regulation of conditioned fear and its relation to extinction. *Neuron*, *59*(5), 829–838. https://doi.org/10.1016/j.neuron.2008.06.029

Ditye, T., Jacobson, L., Walsh, V., & Lavidor, M. (2012). Modulating behavioral inhibition by tDCS combined with cognitive training. *Experimental Brain Research*, *219*(3), 363–368. https://doi.org/10.1007/s00221-012-3098-4

Engelmann, J. B., Moore, S., Capra, C. M., & Berns, G. S. (2012). Differential neurobiological effects of expert advice on risky choice in adolescents and adults. *Social Cognitive & Affective Neuroscience*, *7*(5), 557–567. http://doi.org/10.1093/scan/nss050

Goldstein, M., Brendel, G., Tuescher, O., Pan, H., Epstein, J., Beutel, M., … Silbersweig, D. (2007). Neural substrates of the interaction of emotional stimulus processing and motor inhibitory control: An emotional linguistic go/no-go fMRI study. *NeuroImage*, *36*(3), 1026–1040. https://doi.org/10.1016/j.neuroimage.2007.01.056

Gollwitzer, P. M., & Bargh, J. A. (2005). Automaticity in goal pursuit. In A. J. Elliot & C. S. Dweck (Eds.), *Handbook of competence & motivation* (pp. 624–646). New York, NY: Guilford Press.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral & Brain Sciences*, *24*(5), 849–878. https://doi.org/10.1017/s0140525x01000103

Ji, Y., & Yu, X.(1993).The Self-Esteem Scale (SES). *Chinese Mental Health Journal*, *19*(Sup.), 251-252

Li, C. R., Huang, C., Constable, R. T., & Sinha, R. (2006a). Gender differences in the neural correlates of response inhibition during a stop signal task. *NeuroImage*, *32*(4), 1918–1929. https://doi.org/10.1016/j.neuroimage.2006.05.017

Li, C. R., Huang, C., Constable, R. T., & Sinha, R. (2006b). Imaging response inhibition in a stop-signal task: Neural correlates independent of signal monitoring and post-response processing *Journal of Neuroscience, 26*(1), 186–192. https://doi.org/10.1523/JNEUROSCI.3741-05.2006

Li, W., & Qian, M. (1995). Revision of STAI Norm of College Students in China. *ACTA Scientiarum Naturalum Uuniversitis Pekinesis*, *31*(1). http://doi.org/10.13209/j.0479-8023.1995.014

Liu, X., Zhou, P., & Zhou, Z. (2011). Reliability and Validity of Affective Style Questionnaire Chinese Revised Version. *China Journal of Health Psychology*, *19*(7),874-875. http://doi.org/10.13342/j.cnki.cjhp.2011.07.030

Mauss, I. B., Cook, C. L., & Gross, J. J. (2007). Automatic emotion regulation during anger provocation. *Journal of Experimental Social Psychology*, *43*(5), 698–711. http://doi.org/10.1016/j.jesp.2006.07.003

Motes, M. A., Gamino, J. F., Chapman, S. B., Rao, N. K., Maguire, M. J., Brier, M. R., … Hart, J., Jr. (2014). Inhibitory control gains from higher-order cognitive strategy training. *Brain & Cognition*, *84*(1), 44–62. http://doi.org/10.1016/j.bandc.2013.10.007

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as a limited resource: Regulatory depletion patterns. *Journal of Personality & Social Psychology*, *74*(3), 774–789. http://doi.org/10.1037/0022-3514.74.3.774

Nieuwenhuis, S., Yeung, N., van den Wildenberg, d. W. W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience*, *3*(1), 17–26. http://doi.org/10.3758/CABN.3.1.17

Patterson, T. K., Lenartowicz, A., Berkman, E. T., Ji, D., Poldrack, R. A., & Knowlton, B. J. (2016). Putting the brakes on the brakes: Negative emotion disrupts cognitive control network functioning and alters subsequent stopping ability. *Experimental Brain Research*, *234*(11), 1–12. http://doi.org/10.1007/s00221-016-4709-2

Plutchik, R., & Van Praag, H. (1989). The measurement of suicidality, aggressivity and impulsivity. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, *13*, S23–S34. http://doi.org/10.1016/0278-5846(89)90107-3

Plutchik, R., & Van Praag, H. M. (1995). The nature of impulsivity: Definitions, ontology, genetics, and relations to aggression. In E. Hollander & D. J. Stein (Eds.), *Impulsivity and aggression* (pp. 7–24). Oxford, England: John Wiley & Sons.

Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience*, *6*(7), 576–582. http://doi.org/10.1038/nrn1706

Romer, D. (2010). Adolescent risk taking, impulsivity, and brain development: Implications for prevention. *Developmental Psychobiology*, *52*(3), 263–276. http://doi.org/10.1002/dev.20442

Scheres, A., Oosterlaan, J., & Sergeant, J. A. (2010). Response execution and inhibition in children with AD/HD and other disruptive disorders: The role of behavioural activation. *Journal of Child Psychology and Psychiatry*, *42*(3), 347–357. http://doi.org/10.1111/1469-7610.00728

Srull, T. K., & Wyer, R. S. (1979). The role of category accessibility in the interpretation of information about persons: Some determinants and implications. *Journal of Personality & Social Psychology*, *37*(10), 1660–1672. http://doi.org/10.1037/0022-3514.37.10.1660

Wang, L., Liu, H., Li, Z., & Du, W. (2007). Reliability and Validity of Emotion Regulation Questionnaire Chinese Revised Version. *China Journal of Health Psychology*, *15*(6), 503-505. http://doi.org/10.3969/j.issn.1005-1252.2007.06.034

Wang, Y., Yang, J., Yuan, J., Fu, A., Meng, X., & Li, H. (2011). The impact of emotion valence on brain processing of behavioral inhibitory control: Spatiotemporal dynamics. *Neuroscience Letters*, *502*(2), 112–116. http://doi.org/10.1016/j.neulet.2011.07.039

Wang, Z., Yuan, C., Huang, J., Li, Z., Chen, J., Zhang, H., Fang, Y.,& Xiao, Z. (2011). Reliability and validity of the Chinese version of Beck Depression Inventory-II among depression patients. *Chinese Mental Health Journal*, *25*(6),476-480. http://doi.org/10.3969/j.issn.1000-6729.2011.06.014

Weissman, M. M. (2007). Cognitive therapy and interpersonal psychotherapy: 30 years later. *American Journal of Psychiatry*, *164*(5), 693–696. http://doi.org/10.1176/ajp.2007.164.5.693

Williams, L. E., Bargh, J. A., Nocera, C. C., & Gray, J. R. (2009). The unconscious regulation of emotion: Nonconscious reappraisal goals modulate emotional reactivity. *Emotion*, *9*(6), 847–854. http://doi.org/10.1037/a0017745

Yao, R. & Liang, L. (2010). Analysis of the Application of Simplified NEO-FFI to Undergraduates. *Chinese Journal of Clinical Psychology,18*(4), 457-459. http://doi.org/10.16128/j.cnki.1005-3611.2010.04.024

Yu, F., Yuan, J., & Luo, Y. J. (2009). Auditory-induced emotion modulates processes of response inhibition: An event-related potential study. *Neuroreport*, *20*(1), 25–30. http://doi.org/10.1097/WNR.0b013e32831ac9b1

Yuan, J., Ding, N., Liu, Y., & Yang, J. (2015). Unconscious emotion regulation: Nonconscious reappraisal decreases emotion-related physiological reactivity during frustration. *Cognition & Emotion*, *29*(6), 1042–1053. http://doi.org/10.1111/j.1469-8986.2008.00693.x

Yuan, J., Meng, X., Yang, J., Yao, G., Hu, L., & Yuan, H. (2012). The valence strength of unpleasant emotion modulates brain processing of behavioral inhibitory control: Neural correlates. *Biological Psychology*, *89*(1), 240–251. http://doi.org/10.1016/j.biopsycho.2011.10.015

Yuan, J. J., Xu, M. M., Yang, J. M., & Li, H. (2017). The application of the two-choice oddball paradigm to the research of behavioral inhibitory control. *Scientia Sinica*, *47*, 1065–1073. http://doi.org/10.1360/N052017-00125

Yuan, J., He, Y., Qinglin, Z., Chen, A., & Li, H. (2008). Gender differences in behavioral inhibitory control: ERP evidence from a two-choice oddball task. *Psychophysiology*, *45*(6), 986–993. http://doi.org/10.1111/j.1469-8986.2008.00693.x

Zhao, X., Liu, X. T., Yi, Z. X., Dai, L., & Bao, Z. A. (2015). Response inhibition of cigarette-related cues in male light smokers: Behavioral evidence using a two-choice oddball paradigm. *Frontiers in Psychology*, *6*(1506). http://doi.org/10.3389/fpsyg.2015.01506

Zhou, L., Xiao, S., He, X., Li, J., & Liu, H. (2006). Reliability and Validity of Chinese Version of Barratt Impulsiveness Scale-11. *Chinese Journal of Clinical Psychology*, *14*(4),343-344. http://doi.org/10.3969/j.issn.1005-3611.2006.04.005